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Heat Shrinkable Tubing as Sewer Pipe Joints

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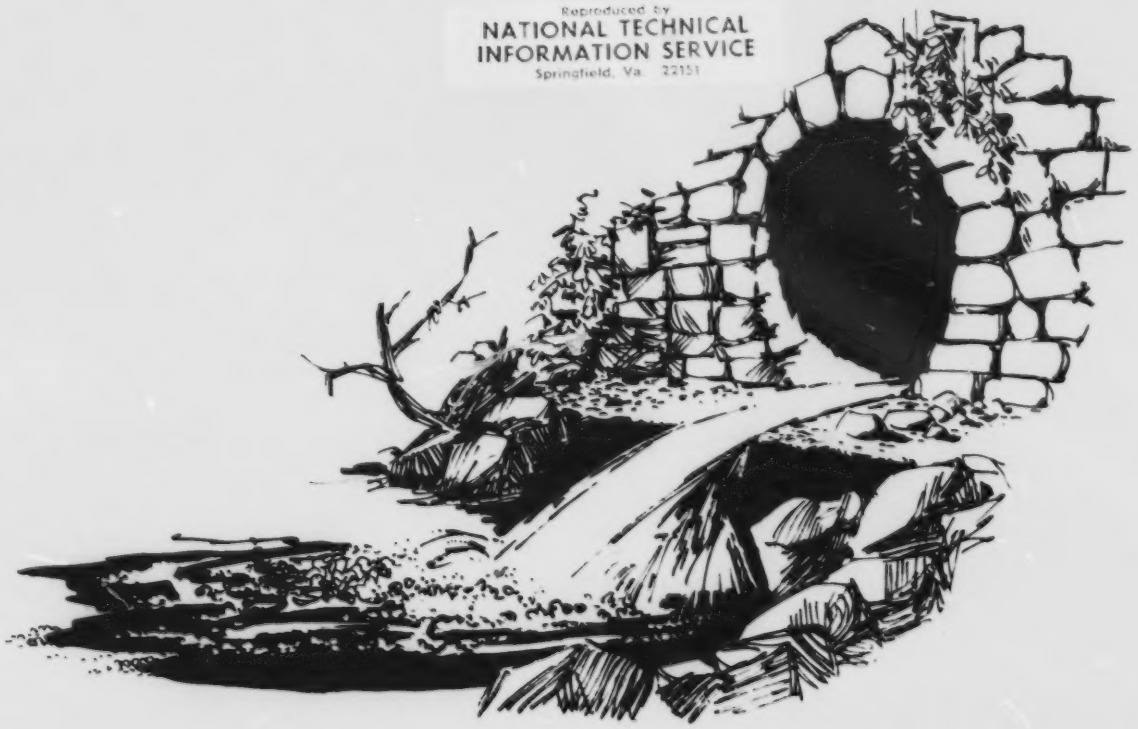

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16. Abstract Preliminary testing had indicated that commercial sewer pipe might be coupled in tight waterproof joints using the heat shrinkable plastic tubing (HST) developed and used extensively in the electronics and aerospace industries. Laboratory studies of such materials and joints were conducted to determine their characteristics and their operational and economic feasibility. A wide variety of HST materials and joints were tested in addition to conventional joints for clay, concrete and asbestos-cement pipes. The results of both small scale tests and full scale tests using commercial 8-inch sewer pipe indicated that a polyolefin with a polymeric base hot melt adhesive produced the most durable, watertight joints and were significantly superior in performance compared to existing pipe joining mechanisms. In addition, the cost analysis indicated that HST joints are economically feasible and compare favorably to conventional joints when considering both material and installation costs. The HST joint requires no significant departure from current installation practice and is equally adaptable to repair of installed commercial pipe and joints. Field development and in-use demonstration of the HST system is recommended. (Poertner)

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HEAT SHRINKABLE TUBING AS SEWER PIPE JOINTS

by

The Western Company
of North America
2201 North Waterview Parkway
Richardson, Texas 75080

for the

WATER QUALITY OFFICE
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ABSTRACT

Preliminary testing had indicated that commercial sewer pipe might be coupled in tight waterproof joints using the heat shrinkable plastic tubing (HST) developed and used extensively in the electronics and aerospace industries. Laboratory studies of such materials and joints were conducted to determine their characteristics and their operational and economic feasibility. A wide variety of HST materials and joints were tested in addition to conventional joints for clay, concrete and asbestos-cement pipes.

The results of both small scale tests and full scale tests using commercial 8 inch sewer pipe indicated that a polyolefin with a polymeric base hot melt adhesive produced the most durable, watertight joints and were significantly superior in performance compared to existing pipe joining mechanisms. In addition, the cost analysis indicated that HST joints are economically feasible and compare favorably to conventional joints when considering both material and installation costs. The HST joint requires no significant departure from current installation practice and is equally adaptable to repair of installed commercial pipe and joints. Field development and in-use demonstration of the HST system is recommended.

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SECTION I

CONCLUSIONS

1. The coupling of commercial sewer pipe, both butt-end and bell and spigot, with watertight joints using heat shrinkable plastic tubing is feasible and economically practical. Used in conjunction with a hot melt adhesive it can surpass in physical and chemical strength any of the conventional joints presently being used with clay, concrete, and asbestos-cement nonpressure sewer pipe.

2. Existing test standards for conventional pipe and joints do not provide a means for uniform comparison between types and are not directly related to in-use needs. These standards are based on the capabilities of the materials used.

3. Of the conventional materials tested, the asbestos-cement pipe and joints tended to perform the best in tests exceeding standard limits. While the existing clay compression coupling joint was most similar in configuration to the HST joint concept evaluated, the cost of the compression coupling was the greatest of all joints tested.

4. Of the materials tested, an irradiated polyolefin and polymeric base hot melt adhesive, such as TPS 10750 tubing by Raychem Corp. and CC 150 adhesive manufactured by H. B. Stuck Adhesives, Inc., were the two components best suited for sewer joint use.

5. The cost to a contractor for HST joint materials, including the adhesive, is estimated at approximately $1.75 per joint for an 8 inch diameter pipe, provided demand justifies sufficiently large volume production of HST. The cost will vary with the size of the pipe.

6. Installation costs for sewer pipe construction are primarily dependent on the size of the pipe and not the type of joint. Available statistics indicate that labor costs account for about 24.0 percent of the total sewer investment cost. These costs are associated with width and depth of trench, ground conditions and weight to be handled.

7. Some reductions in sewer installation costs can be anticipated using HST joints. These are all related to elimination of the bell through reduced breakage in handling, elimination of the need for undercutting the trench bottom, backfill tamping under the pipe, etc. Opportunities for improvements in sewer line placing methods (and cost reductions) may exist, based on the strength of the HST joints.

8. The only added installation cost associated with the use of HST joints is a heat source. The cost of providing this equipment will vary depending on the sophistication employed. However, a simple, but adequate, hand operated device could cost as little as $50.

9. The HST joints can be installed using unskilled, or semi-skilled labor. There need not be any significant departure from current installation practice.

10. Available statistics indicate that the cost of joint materials account for about 23.3 percent of the total sewer investment cost. The statistics do not directly identify these costs on a per joint or unit length basis.

11. The key element in the economic evaluation of HST joints is the cost of providing the bell and joint materials for conventional joint systems. A definite determination of these costs (and the cost reductions possible through elimination of the bell and materials) cannot be made at this time due to the proprietary nature of such information.

12. The direct manufacturing costs for 8 inch clay and concrete pipe can be estimated at $3.35 and $2.91 respectively using quoted sales prices and industry operating statistics. The added costs, improved joint characteristics and reductions in repair and maintenance costs associated with the use of HST joints must be compared with potential reductions in existing manufacturing costs (and resulting sales prices) available through the elimination of the bell and joint materials in conventional systems.

SECTION II

RECOMMENDATIONS

The polyolefin heat-shrinkable tubing should be spotted with a heat sensitive paint to insure that enough heat reaches all surface areas of the joint. A heat sensitive paint, which changes colors at a prescribed temperature would aid both the installer and the inspector of the sewer line in determining that all of the joint was heated sufficiently.

The tubing should be sized as close to the outer diameter of the pipe as convenient placement will allow to reduce shrink time and product cost.

The hot melt adhesive should be applied to the inside of the HST material by the manufacturer to ease installation and storage.

One end of each section of plain-end pipe should have a bumper material permanently attached to it to reduce chipping and cracking of the sewer pipe during and after installation.

The heat source should be gas, either from a torch or a catalytic heating device to eliminate the need for electricity in the trench. The heating device should encompass the heat shrinkable tubing joint in order to shorten shrink time and maintain a uniform shrinkage of the HST material.

Field installation of test sewer lines with the recommended HST joints should be initiated at as early a date as possible to permit observation of the joints under full use and aging, compare performance with installed conventional joints and verify installation procedures. Such a demonstration should be conducted over a period of at least two years.

Uniform test standards for sewer pipe should be developed. These standards should be based on in-use needs and requirements and not the capability of materials used. Such standards would provide incentive and a basis for development and use of improved materials and systems.

Development of new concepts in sewer construction techniques promising improvements in cost and quality of work should be pursued. Development of such concepts, based on the strength of HST joints, should be initiated once the performance of HST joints is verified in field use.

SECTION III

INTRODUCTION

Purpose and Scope

The purpose of this program was to determine the feasibility and installation requirements for using heat shrinkable plastic tubing (HST) as a sewer pipe joint mechanism. This was accomplished through a systematic laboratory analysis of materials and procedures applied to three types of sanitary sewer pipe on the market today. The bases of comparison were the conventional sewer pipe joints now in use.

It was not the purpose of this program to develop or recommend new test procedures for sewer pipe joints, evaluate existing pipe materials, or demonstrate definitive installation practices for the HST system.

Background

For several thousand years sewage has been transported in some form of collection system. From the Roman period to the early 1900's the primary objective was to get the sewage of communities out of sight and out of the way. Today, with the population of the United States growing at a rate of 100,000 people per month, it is no longer possible to rid our cities of their sewage by simple diversion to the outskirts of the more populated areas. All sewage must be disposed of and returned to the environment in a form acceptable to all plant and animal life. The standards of disposal are continually becoming more stringent.

One of the most significant problems with sewage collection systems in cities today is the exfiltration of sewage and infiltration of water through deteriorated or leaking lines. Infiltration of rain water into a sewer system after a heavy rain costs local taxpayers thousands of dollars each year as a result of excessive demand placed on the system. Environmental degradation results from overflows in the line and at the treatment plant.[1,2,3,4,5] More tangible costs result from the added investment in capacity of lines and plants to treat this overburden. In turn, the exfiltration from a sewer line in dry weather deposits raw sewage beneath communities or permits uncontrolled drainage without treatment.

The joint between each section of sewer pipe can be identified as a primary source of exfiltration and infiltration in a sewer system.[2,3,4,5] The conventional joint system also presents several inherent difficulties to sewer contractors and pipe shippers. It is subject to:

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Breakage of the bell in shipment, storage, and installation.

Higher costs resulting from the bulkiness of the bell in shipment and storage.

Time lost in undercutting the trench to receive the bell.

Bell breakage resulting from the backfilling operation and in later soil shifting.

After considering these facts, it becomes evident that a sewer line without the bell might eliminate many of the problems and costs facing the sewer industry, provided a watertight joint can be made.

It was proposed that a sewer line composed of plain-end (without bells) sewer pipe could be laid and heat shrinkable plastic tubing (HST) positioned at the joints. Heat would then be applied to the tubing, and the HST would shrink in diameter around the pipes forming a tight waterproof joint. An added feature of the proposed system would be that an existing supply of bell and spigot pipe could also be used while retaining the benefit of a waterproof seal. By using a heat shrinkable sleeve over a conventional bell and spigot joint, the plastic will shrink tightly around the bell and spigot to form a strong leakproof joint as shown in Figure 1.

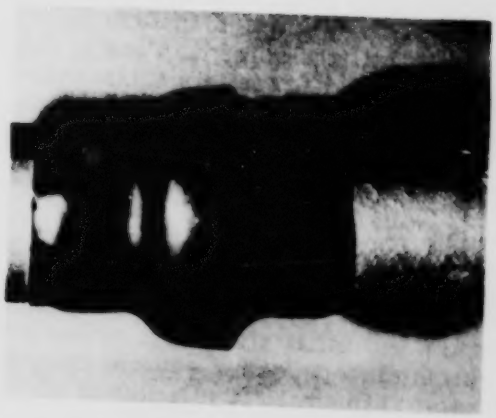


Figure 1. Heat Shrinkable Tubing Recovered Over Bell and Spigot Pipe

The joining capacity of the HST could not be limited only to straight lengths of pipe, but had to be adaptable to wyes, tees, skew joints, etc. In addition, one of the operating problems faced by pipe installation crews is the connection of house laterals or tie-ins where no adapter has been placed in an existing line. By using an HST boot or adhesive wrap, these connections might be efficiently secured and sealed. Figure 2 depicts this latter situation.

The most common types of sewer pipe in use today are clay, concrete, composition (asbestos-cement), plastic, and cast iron. It was the intent of this program to unite the strength of these pipes with the waterproof sealing capabilities of heat shrinkable tubing. The program concentrated on applications with clay, concrete, and asbestos-cement pipes as these represent the majority of below ground sewer installations.

Program Description and Approach

Due to the large number of heat shrinkable materials currently on the market, it was necessary to structure the initial portion of the program as an identification and screening process. As part of this first phase, a review of the literature on heat shrinkable materials was conducted to identify a complete list of candidate materials, their manufacturers, product characteristics, existing applications and use practices. Performance measures and a test scheme to develop those measures for each material were developed.

All potential materials as well as the components of conventional sewer pipe joints were exposed to a series of chemical resistance tests. The heat shrinkable materials were subjected to tests for physical properties and strength as joints on controlled specimens of small diameter (1 inch I. D.) pipe. The materials which performed best under these screening tests were selected for full scale tests on commercial sewer pipe.

The second phase of the program consisted of tests for physical properties and strength of three HST materials as joints on 8 inch diameter commercial sewer pipe of clay, concrete and asbestos-cement. The same tests were also performed for the conventional joints currently used with each of the pipe types so that direct comparisons could be made.

The second phase also included an investigation of the cost of HST materials, conventional sewer pipe joints and sewer construction to identify the economic feasibility of the proposed joint concept.

During the final portion of the program an evaluation was made of the potential of the HST joint for installed sewer pipe and joint repair. In addition, systems and methods for installation of HST joints were identified and evaluated based on the test experience and current practice.

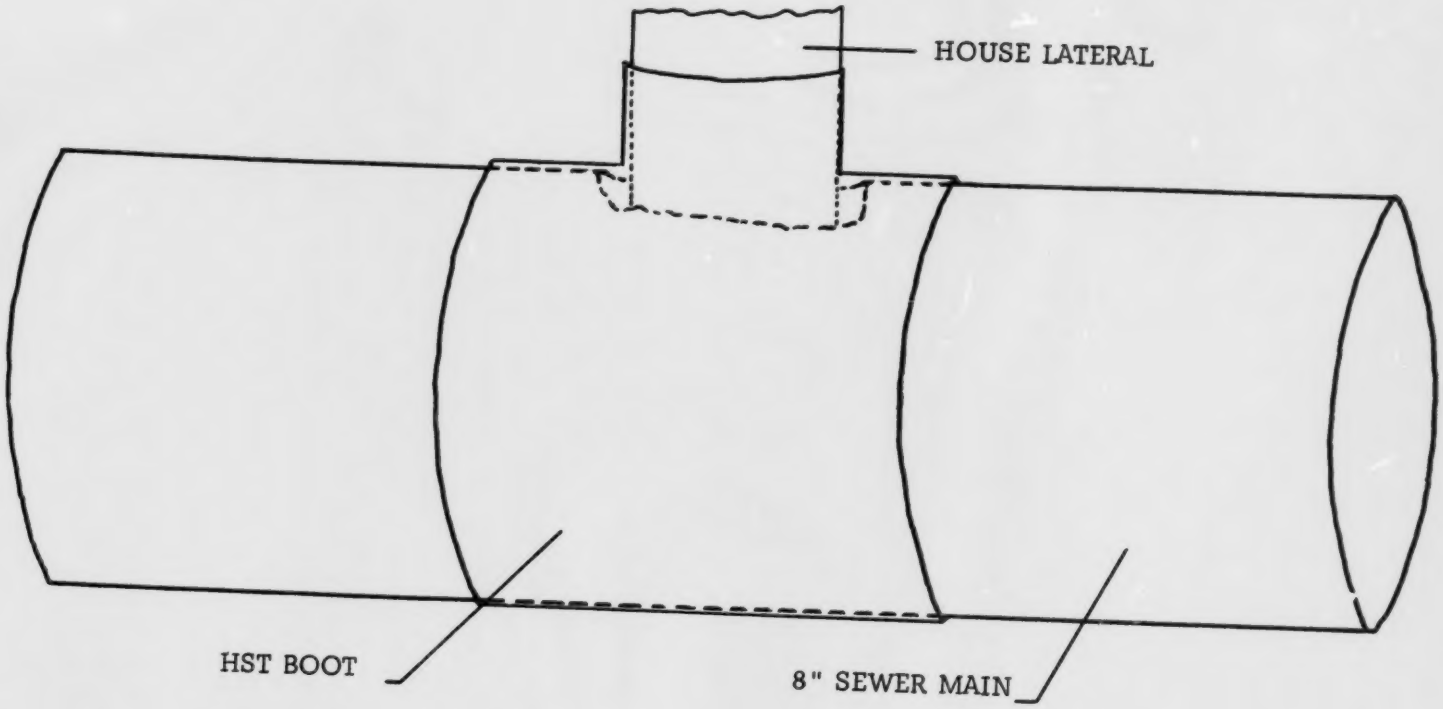


Figure 2. Heat Shrinkable Tubing Boot Used to Connect House Laterals

SECTION IV

OBJECTIVES

A group of six specific objectives was defined for the program. From these objectives a plan of operation was developed which guided the conduct of the investigation and evaluation. The emphasis of the objectives is on the comparison of the heat shrinkable joint concept with existing systems rather than establishing absolute measures of evaluation.

1. Determine the feasibility of the heat shrinkable joint concept by

   - identifying potential HST materials and potential limitations on their suitability relative to -
     - cost
     - special chemical and physical characteristics
     - manufacture of special size and shapes
     - formulation changes for special properties
     - delivery capability

   - defining the characteristics of the proposed application -
     - soil loads
     - sewage composition
     - current standard joint tests and requirements
     - pipe properties
     - installation methods

   - conducting laboratory evaluations of the identified HST materials to rank and screen the candidates relative to -
     - physical properties and strength
     - chemical properties and resistance

   - conducting laboratory evaluation of conventional joint materials for chemical properties and resistance for comparison with the HST materials

2. Select the four most promising HST materials resulting from the feasibility study for further test, evaluation and comparison with conventional joints.

3. Determine the extent of improvement in joint performance using the four candidate HST materials as compared to conventional joints by:

   - conducting tests for physical properties and strength of the HST joints on commercial 8 inch sewer pipe.

   - conducting tests for physical properties and strength of conventional joints on commercial 8 inch sewer pipe.

4. Determine the cost effectiveness of HST joints by comparing material and installation costs with relevant costs using conventional joints.

5. Define the applicability of HST joints to use in repair of installed sewer lines.

6. Recommend the best HST materials, application methods and associated equipment for further testing and demonstration based on optimum joint performance and ease of installation.

SECTION V

CURRENT PRACTICE AND MATERIALS

Heat Shrinkable Tubing

Heat shrinkable tubing begins as ordinary plastic or rubber compounds which are then extruded into sections of tubing. The irratiated types of HST are bombarded with high energy electrons to link the molecules providing a high temperature burn point for the material. Non-irratiated tubing does not exhibit resistance to high temperature. The tubing is then heated and stretched in diameter, but not in length. After it cools, it retains the expanded diameter. As a result of this process, when the HST is reheated, it will recover in diameter only.

If a length of 8 inch diameter tubing is expanded to 16 inches, it will conform to any shape between the 8 inch and 16 inch diameters, when reheated. This characteristic gives the HST the ability to form a tight fit around both the bell and the barrel of the sewer pipe as shown in Figure 1. At the present time, HST is primarily used for covering electrical components and roll covers. The materials offer flexibility, temperature resistance, and chemical resistance, all of which are necessary for applications in a sewer system.

The tubing can also be provided with an inner liner of hot melt adhesive. At normal temperatures these adhesives are smooth, non-tacky and resemble a plastic coating on the tube. As the tube is heated for shrinking, the adhesive changes in character, becomes tacky, and adheres to surfaces with which it comes in contact. After cooling, the adhesive solidifies once again forming a tight bond with the contact materials. An optimum system of this sort requires that the adhesive suitable for proper bonding with the contained material have a melt point consistent with the recovery temperature of the HST used.

There are a host of materials classified as "heat shrinkable" manufactured by a wide range of organizations. The materials are offered in a variety of characteristics and sizes. However, due to their applications to date, the majority of tube products are available in small diameter (less than 3 inches). Appendix I represents the most pertinent results of a review of literature, manufacturers and information relating to heat shrinkable materials and tubing. This review coupled with interviews with manufacturers and suppliers formed the basis for selecting candidate materials.

Heat Source

The proper heat source is important in reducing shrink time and providing even shrinkage of the material. The temperature at which the heat shrinkable tubing will begin to recover varies for different types of HST from

150°F to 650°F. In addition, there is an upper limit of temperature above which each material will burn. Considering these variations, four heating devices were considered during the program.

A hot air gun[6] was used during the first part of the small scale laboratory testing. The main body of the heat gun consists of a small air blower and heating coils. It is powered by electricity and develops heat up to 1000°F. The heat gun delivers hot air at 8.82 cubic feet per minute at a velocity of 1400 feet per minute. It requires 115 volts AC and 20 amps of electricity. The hot air gun is adequate for recovering tubing up to 2 inch expanded diameter.

An iodine quartz lamp[7] emits infrared heat up to 750°F. It requires 115 volts and 2.1 amps of electricity. The manufacturer stipulates approximate bulb life at 2,000 hours. The iodine quartz lamp was not used during this program, but representatives were consulted on its abilities and limitations. The lamp easily recovered HST up to 2 inch expanded diameter. In order to recover an 8 inch piece of HST, however, several lamps would be needed to maintain shrink time at two or three minutes.

Both the hot air blower and the iodine quartz lamp require electricity. In sewer pipe joint applications this would require a generator at the installation site and electricity down in the trench. The equipment necessary to link several of these heating devices together to encompass the joint would be bulky and hard to handle. Additional costs would arise from repair of air blowers and electric generators. After making these observations, gas heaters appeared better suited to the HST sewer pipe joint concept.

Using a hand held propane torch,[8] 8 inch HST joints can be recovered in less than three minutes. With a torch pressure of 4.0 psi the torch will deliver a yellow-orange flame 20 inch in length. The approximate heat output would be 83M btu/hr, at a propane consumption rate of 5.1 lbs/hr. By removing the torch head and attaching a hinged collar with rows of small gas jets circling the inner diameter, an even heat could encompass an HST joint. No electricity would be needed in the trench and there would be no moving parts to repair.

Catalytic heaters[9] offered another source of heat derived from propane or butane gas. A catalytically active metal screen converts the gas to infrared energy and in turn supplies heat to recover the joint. The screen encompasses the joint material to provide uniform shrinkage of the HST. Like the gas torch, it requires no electricity and has no moving parts.

Sewer Pipe Joints

Pipe connections used by the sewer industry today include mortar, asphaltic base materials, lead, rubber gaskets, "O" rings, bands, clamps, and numerous other combinations and variations used in conjunction with a

bell and spigot or tongue and groove coupling mechanism. All of these joints are designed to provide two things, a leak proof seal and flexibility. With any type of bell and spigot or tongue and groove joint, shifting soil or improper trench preparation can cause unnecessary stress on the pipe or a deflection of the sewer pipe past a maximum for which its joint is designed resulting in a leak at the joint. The problem of flexibility is further restricted by pipe alignment, which must be maintained to prevent obstructions in the sewer line and provide full capacity of the pipe installed.

In general, the manufacturers of various types of sewer pipe (clay, concrete, cast iron, etc.) have each developed, and provide as part of the pipe, a complete joint mechanism, or recommend materials and procedures to be used in fabricating a joint.

Sewer Pipe Installation

The installation of sewer pipe is often considered to be a simple task. This opinion probably stems from the assumption that anyone can dig a ditch. Physically digging a ditch is not all that is involved in making a good excavation. The width of the trench must be determined by the type of soil, depth of laying, type and size of pipe and excavating equipment, and the space required to allow workmen to backfill thoroughly around and under the pipe. Consideration must be given to safe operation, water fill up, proper backfill and supports. Several types of trenches can be prepared for pipe installation:

1. flat bottom trenches, where backfill is tamped or not tamped
2. trenches having blocks to support the pipe and the backfill is tamped or not tamped
3. trenches having bottoms shaped to fit the bottom of the pipe

Due to the presence of the bell on the majority of sewer pipe, the latter two types of installations are generally required. When supports are used, it is necessary to backfill and tamp beneath the pipe. Without this, the backfill overburden will create undesirable stress on the pipe and the bell due to the void left beneath the pipe. This condition leads to pipe cracks, cracked and broken bells and leaks. When supports are not used and bottom shaping to fit the bell is not accomplished, the same conditions can also develop.

Handling the pipe above ground and placing it in the trench are important considerations. Permitting the bell or spigot to strike objects or other pipe contributes to cracking and chipping, seriously affecting the quality of resulting joints.

Finally, improper backfilling and compaction can break the pipe or joint once in the ground or deflect or dislocate it exceeding the joints' flexibility and destroying its seal.

It is evident that installation practice is critical to joint performance. The practice must match the needs of the materials. The best designed joint is useless if total installation is not accomplished properly.

Joint Requirements

To satisfy a broad range of performance requirements, the pipe industry utilizes a number of different joints. Pipe joints can perform a variety of functions depending upon the type of pipe and its application. The selection of a proper joint may be determined by the performance required of it. Joints can be designed to provide:[12]

1. Resistance to infiltration of ground water and/or backfill material.
2. Resistance to exfiltration of sewage.
3. Control of leakage from internal or external heads.
4. Flexibility to accommodate lateral deflection or longitudinal movement without creating leakage problems.
5. Resistance to shear stresses between adjacent pipe sections without creating leakage problems.
6. Hydraulic continuity and a smooth flow line.
7. Controlled infiltration of ground water for subsurface drainage.
8. Ease of installation.

The primary source of definitive standards of performance for sewer pipe joints are those set forth by the American Society for Testing and Materials (ASTM) specifications. Specifications are given by types of pipe material and joint mechanism and for sizes of pipe of each type. During this program, clay, concrete and asbestos-cement pipes were used in testing. The following ASTM specifications were found to be relevant to the test program:

ASTM C425 66T Compression Joints for Vitrified Clay Bell and Spigot Pipe

ASTM C443 70	Joints for Circular Concrete Sewer and Culvert Pipe, Using Rubber Gaskets
ASTM C428 69a	Asbestos-Cement Nonpressure Sewer Pipe
ASTM C584 66T	Compression Couplings for Vitrified Clay Plain-End Pipe

Pertinent extracts from these specifications are given in Appendix II. Various sewer design and construction manuals were also reviewed,[10,11,12] however, the ASTM's were found to be the most pertinent and formed the basis for the tests conducted during the program.

ASTM specifications have been particularly useful over the years in helping to standardize industrial processes and products. By establishing a basic level of performance for a product, they benefit manufacturers as well as users. The standards are, in general, based on the capabilities of a material or design as sponsored by a technical committee and accepted by the Society.

It should be noted that there are some shortcomings or inconsistencies in all specifications for sewer pipe joints. The most significant of these is that all sources of these specifications permit some level of leakage for new installation. Design manuals refer to leakage as "design infiltration" (or exfiltration), or "permissive infiltration" (or exfiltration). All assume some leakage as acceptable presumably under potential operating conditions. It would be expected that such built-in leakage would only increase with aging. In addition, the ASTM's specify different standards for the different pipe materials. For example, one type of pipe joint must withstand a hydrostatic pressure of 10 psi for 10 minutes while another must withstand only 4.3 psi for 60 minutes to meet specifications. As a result, the two pipe joints cannot be readily compared as to performance for use in a given installation. Both, however, are being used interchangeably on the job for the most part. While these specifications are adequate for establishing base line manufacturing standards, they do not present a uniform standard relative to on-the-job performance. It is recommended that attempts be made to establish uniform standards based on the requirements and needs of the job.

Loading and Forces

Sewer pipe is installed in relatively narrow trenches and covered with earth backfill to the original ground surface. Load on the pipe develops as the backfill settles and is equal to the weight of the material above the top of the pipe minus the shearing or frictional forces on the side of the trench. If the size of the pipe, width of the trench, and depth of the trench are known, one can easily determine soil loads from prepared

charts developed by the pipe industry.

While soil loads are important to pipe manufacturers in the design of pipe to withstand high external loads, they were not considered of great importance in the HST pipe joint evaluation. (In this respect soil load was considered distinct from shear forces, which result from soil shifting). Since the concept involved joining ends of pipe, the HST would be supported by the pipe structure which in turn supports the overburden and external hydrostatic pressure.

The shear forces which act upon a sewer system are critical to pipe joints. If the soil beneath a pipe settles, support is provided only by the joints on both ends or to the next supported pipe section. The overburden must be supported by the joint strength or extreme deflection and failure can occur.

During periods of infiltration or other peak loads, hydrostatic heads develop. The ASTM specifications recognize each of these conditions as well as the combined effect. Internal hydrostatic forces produce longitudinal tensile forces within the pipe. This condition has negligible effect when considering a pipe buried in the ground, but is quite important when considering a test stand evaluation. Due to the forces present, the pipe will attempt to separate at its weakest point in tension (the joint) and must be constrained.

Sewage Composition

Sewage composition can vary widely between different geographic areas. In order to produce a synthetic or manufactured sewage for laboratory experimentation, several Environmental Protection Agency [12, 13, 14, 15] publications and ASTM specifications (Appendix B) were consulted. The components of presently accepted synthetic sewage were the basis for the chemical resistance tests conducted in this program.

SECTION VI

SMALL SCALE LABORATORY TESTING

Test Procedures

The small scale laboratory testing conducted as Phase I of the program was essentially a screening process for a large group of HST materials. The test procedures used for the screening were established after considering available information relating to such factors as soil loads, sewage composition, installation procedures, and joint requirements.

Material Preparation

All test specimens of HST had an expanded diameter of 1.25 inch to 2 inches and a recovered diameter of 1 inch. Upon receiving a sample of HST from the manufacturer, several preliminary steps were followed.

1. The HST was cleaned of any dirt or oil collected during shipping.
2. The HST was cataloged and cut in 3 inch pieces.
3. The manufacturer's data sheet was consulted for the recommended application procedures.
4. Specimens were recovered with hot air and with a gas torch to determine the best heat source for each material.
5. Each type of HST was checked for flammability.

Upon completion of these preliminaries, the HST was ready for the small scale laboratory tests. There were two groups of tests. The physical property tests revealed the mechanical strength of the HST materials, while the chemical resistance tests showed any vulnerability to chemicals or bacterias.

Pipe Preparation

For the sake of reproducibility in testing and adaption to test apparatus, porcelain coated cold rolled steel pipe was used as simulated sewer pipe for the screening tests. Each pipe was 8 inches long and 1.20 inch in outside diameter. This simulated sewer pipe had several advantages over other various substitutes for sewer pipe in this size. A controlled bonding surface was available. The threaded end made it adaptable to test apparatus. It could withstand higher pressures than the HST joints. It was reusable.

Tensile Test

The objective of the tensile test was to determine the force necessary to longitudinally separate the joined pipe. A Dillion Dynamometer was used to measure the force necessary to part the joint. For the tensile test, the joint was formed with HST and pipe caps were placed on the threaded end of each pipe. The joint was then placed into the Dynamometer by attaching the pipe ends to the two opposing heads. Force was applied until the joint separated. The highest reading in pounds was taken and converted into psi using the formula:

$$psi = P \div (3.14 \times D \times L)$$

A tensile test is not incorporated in the ASTM's since pipes in the ground are butted together and constrained from longitudinal movement. The test was included in the program to evaluate the relative grip strength of recovered HST. Consideration was also given to the potential for differential movement between sewer lines and house laterals.

Figure 3. Dillion Dynamometer Tensile Test Apparatus

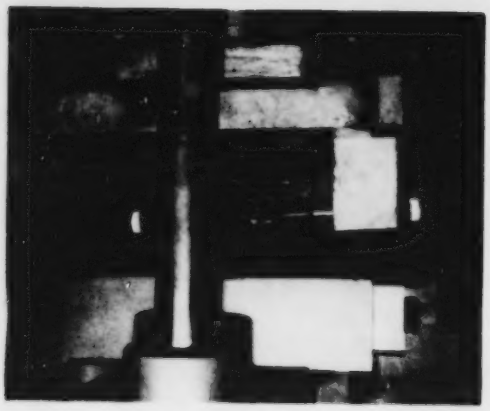


Figure 4. Budd Press, Shear Test Apparatus

Shear Test

The shear test was conducted to record the amount of pressure necessary to separate the joint with forces applied perpendicular to the joint, such as with differential settlement. A Budd Press was used in this test by mounting holding blocks on the two opposing heads. Each holding block was 10 in. x 4 1/2 in. x 3 1/4 in. with a hole slightly larger than the outer diameter of the test pipe. One holding block was mounted on the stationary head of the press and the second block was mounted to the moveable head of the press, with the holes in alignment. The HST pipe joint was inserted through the aligned holes and the press closed to apply shear loads perpendicular to the joint axis. When the joint separated, a failure was noted and the pressure in pounds recorded. To determine what shear load the 1 inch HST joint had to withstand to model full scale joint action, calculations were made based on the basic Stress = Load/Area formula. These calculations are detailed in Appendix C.

Internal Pressure Test

For the small scale internal pressure test, a bladder accumulator was used to maintain a constant pressure over a wide range of values. The test specimen, line, and one side of the accumulator were filled with water. The opposite side of the accumulator was connected to an air compressor. Air forced into the accumulator applied pressure to the sealed water system on the opposite side. Any leakage of the joint was noted as a failure and the pressure recorded.

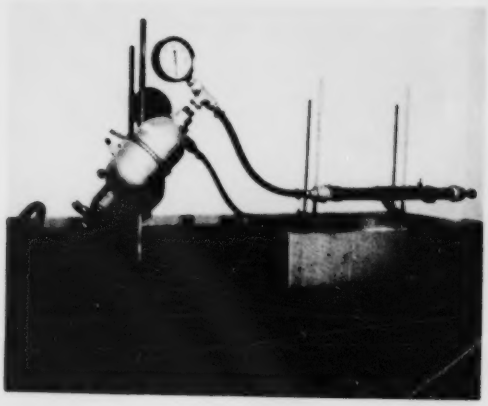


Figure 5. Internal Pressure Test Apparatus

Thermal (Hoop) Pressure Test

This test was designed to determine the amount of hoop pressure exerted by the HST as it shrinks around the outer surface of the pipe. The hoop pressure and rigidness of the HST would be necessary to maintain pipe alignment. In conducting this test, a stainless steel pipe 17 inches long and 1 1/4 inch outside diameter was used. The pipe was cut down both sides from the ends to the middle leaving a 1/4 inch pivot point in the center. A dial indicator was mounted on one end and calibrated to pounds of pressure applied to the opposite end. The test procedure consisted of placing the HST on the end of the stainless steel pipe and shrinking it. An initial reading was taken immediately after recovery and a secondary reading was taken after the HST cooled. By using the formula psi = P ÷ (2 x T x L), the reading in pounds was converted to psi applied by the HST.

Figure 6. Thermal (Hoop) Pressure Test Apparatus

Chemical Resistance Tests

Although an HST material may have had the right physical characteristics for a sewer joint, it would still be of little use if it could not withstand the chemicals which pass through it on a daily basis. Based on a review of actual industrial, city, and recommended synthetic sewage each of the HST materials was subjected to the tests shown in Table 1 for 1000 hours. Specimen preparation for the chemical resistance tests began by cutting each piece into half inch widths. Each one was then heated to its recovered diameter and weighed on a triple beam balance. The size of each specimen was measured by a vernier caliper. After all data was logged, the specimens were placed in a separate glass vial and half submerged with a chemical solution. The glass vials were in turn placed in ovens set at various temperatures. The bacteria, fungus, and enzyme cultures were predeveloped and each specimen was suspended, half submerged, in the broths.

Materials Tested

Whenever possible, two name brands of each type of material were acquired for testing. It was felt that different manufacturing procedures and compounds could produce variations in physical and chemical properties. Appendix D lists all materials tested during the program by generic name, trade name and manufacturer.

Physical Properties

Results of the Physical Properties Tests are presented in Figures 7 - 10. It was found during the preliminary testing and literature search that some heat shrinkable tubing, as supplied by the manufacturer, was unsuitable for use. Both of the neoprene HST tested were canceled after the preliminary tests. Extreme care had to be used to keep this material from getting too hot during shrinkage or the outer surface would bubble and burn. They would not recover to their original diameters and large gaps formed between the HST and the pipe. Neoprene is a very good insulator for electricity and this material is largely used for wire coverings. For this application, it is heated in an oven over a prolonged period of time and satisfactory covering is obtainable. For a pipe joint, however, this procedure is not practical and testing was discontinued.

As with the neoprenes, similar problems arose with the TFE Teflons. Both of the TFE Teflons exhibited curling of the ends, uneven shrinkage, and large gaps between the HST and pipe. Since a leak proof seal was not possible, testing was discontinued.

Chemical	Mixture	Temperature
HCL Acid	99.75 parts water .25 acid	125°F
H_2SO_4	99.75 parts water .25 acid	125°F
H_2O (Tap)	100%	125°F
H_2S	Saturated	125°F
Alconox (Soap)	99.00 parts water 1.00 soap	125°F
Hydrogen Peroxide	99.00 parts water 1.00 oxidizer	125°F
Sodium Hypochloride	99.00 parts water 1.00 chlorene	125°F
Sodium Hydroxide	99.00 parts water 1.00 alkali	125°F
Calcium Hydroxide	99.00 parts water 1.00 alkali	125°F
Gasoline & Naptha	50% each	Room Temperature
Motor Oil	100%	125°F
Isopropyl Alcohol	100%	Room Temperature
Methyl Alcohol	100%	Room Temperature
Uric Acid Urea compounds	1.00 .50 98.50 parts water	125°F
Bacteria Enzymes Fungus	Each separate with water	100°F

Table 1. Chemical Resistance Tests I

Since most HST is used to cover electrical wiring and components, it was not always possible to find two manufacturers of an HST material over 1 inch diameter. This was the case with polyvinyl chloride (PVC) HST. Several companies manufacture PVC HST, but not up to 1 inch recovered diameter. After testing the only PVC material received which would fit the test apparatus, it could not be determined if this material could be made to work on 8 inch diameter pipe. The thermal pressure test yielded low values, which showed that a tight fit was not developed. The PVC also failed the internal pressure tests because of the small recovery ratio, although it did recover uniformly.

The two polyolefin HST materials passed all tests except for the internal pressure tests. This material had a very short recovery time (less than 15 seconds on 1 inch diameter) and would not burn when heated with a propane torch. It is very inexpensive and easily available in sizes up to 60 inch diameter. After applying an adhesive to the inside of the polyolefin, it withstood a maximum internal pressure of 60 psi for two hours with no leakage.

Only one silicon rubber HST was tested. It passed all of the physical property tests and had very good flexibility.

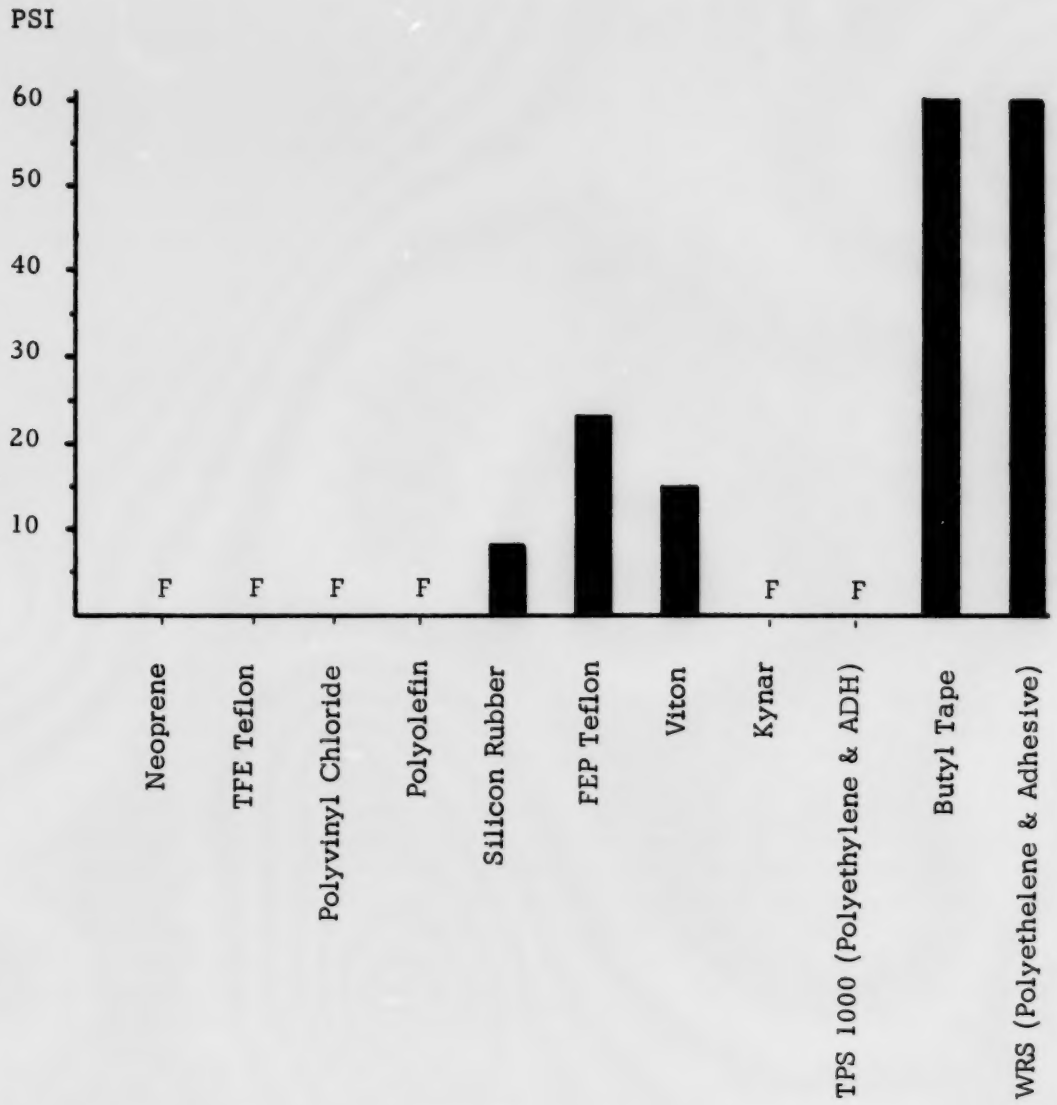
Overall, the FEP Teflons were the best type of HST tested. They had the highest thermal pressure and internal pressure test results (without adhesives). They passed the other two physical property tests, were easy to handle, and recovered very quickly.

Viton also appeared easily adaptable to sewer pipe joints. It was more flexible than the teflon, and maintained almost equal test results. It recovered easily and resisted moderate flame.

The Kynar HST material presented some of the problems previously encountered with the neoprenes and TFE Teflons, uneven shrinkage with gaps between the pipe and tubing, curling of the ends, plus splitting when excessive heat was applied. It was very difficult to get enough joints to test, due to the splitting of the kynar where it was cut. It passed all tests with the exception of the internal pressure tests. After evaluating this material, it was felt to be unsuitable for pipe joints due to brittleness, gaps and air pockets formed on the pipe, and difficulties of application.

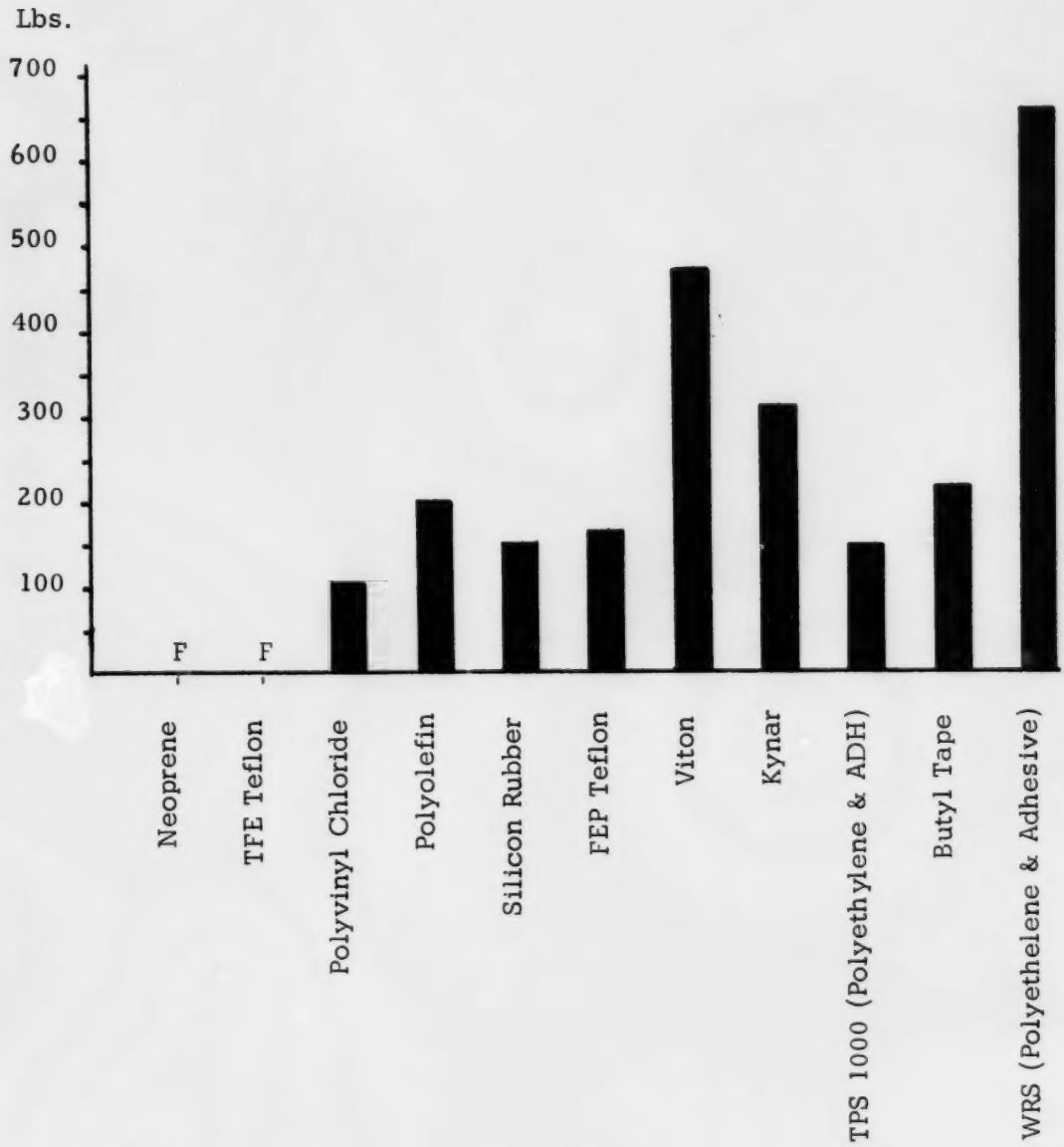
Chemical Resistance

After completing the chemical resistance tests (Table 1) and evaluating the results, some discrepancies were noted. Materials such as teflon and polyolefin which should have had no change in size or weight, showed as much as a 25% change in some chemicals. It was determined that the error inherent in the triple beam balance used was large compared



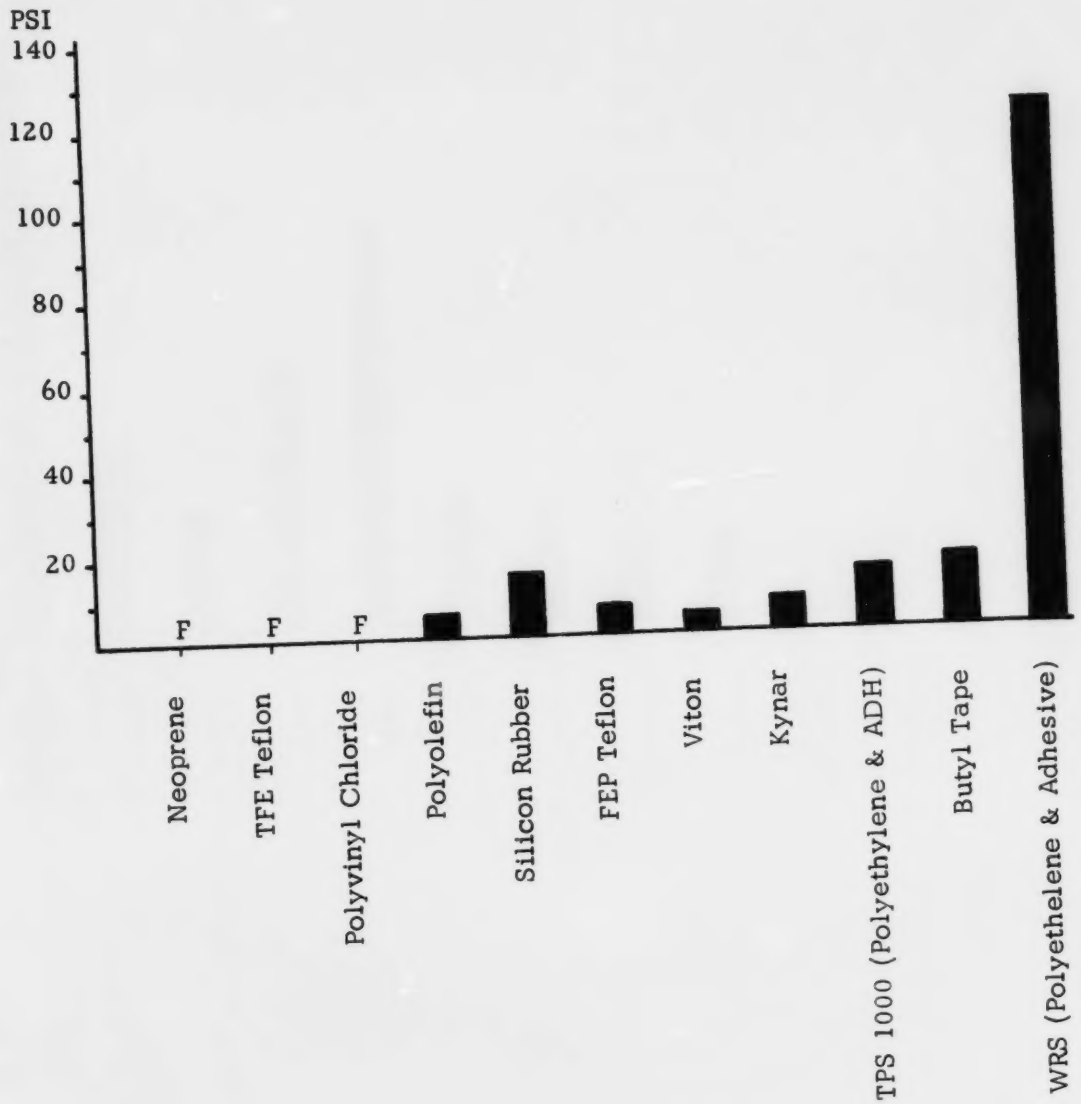
"F" denotes failure.

Figure 7. Small Scale Internal Pressure Test Results



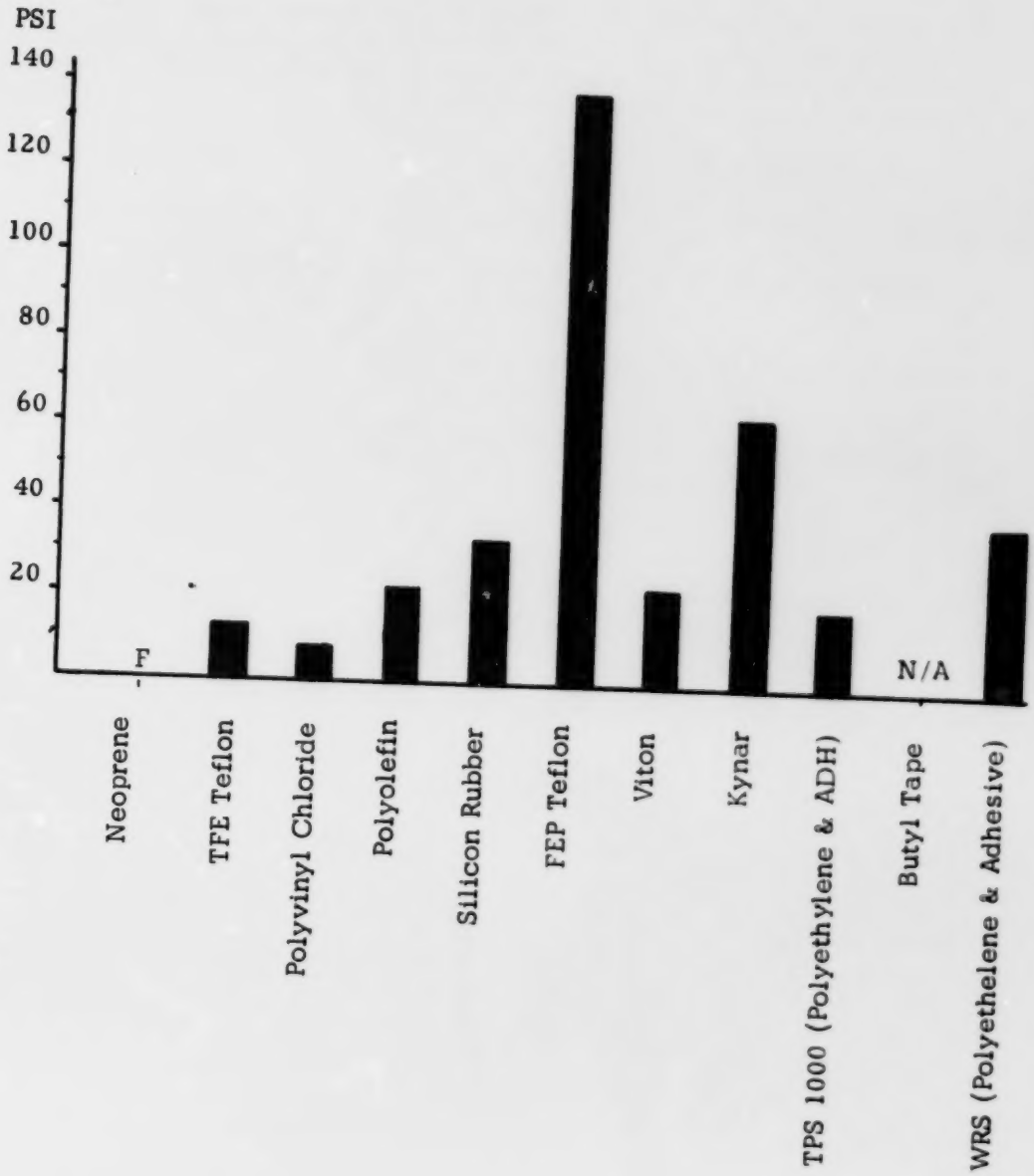
"F" denotes failure.

Figure 8. Small Scale Shear Test Results.



"F" denotes failure.

Figure 9. Small Scale Tensile Test Results



"F" denotes failure.

Figure 10. Small Scale Thermal (Hoop) Pressure Test Results

to the specimen weight. Possible changes in specimen weight were lost in measurement error. A second chemical resistance test series, as described by Table 2, was conducted on the materials which showed the most promise from the physical property tests.

Chemical	Mixture	Temperature
Isopropyl Alcohol	100%	Room Temperature
Hydrochloric Acid	99.75 parts water .25 acid	125°F
Calcium Hydroxide	99.86 parts water 20 oxidizer	125°F
Sulfuric Acid	99.75 parts water 25 acid	125°F
Gasoline	100%	Room Temperature
Sodium Hypochloride	99.00 parts water 1.00 bleach	125°F

Table 2. Chemical Resistance Tests II

Four samples of FEP teflon, polyolefin, and polyvinyl chloride were exposed to each chemical. The specimens were cut into three inch lengths and three of the four were heated in an oven to produce complete recovery. The fourth specimen was left in its expanded form to check for changes due to improper shrinkage. The specimens were then weighed on a torsion beam balance to the nearest .001 gram. In lieu of measuring the size with the vernier calipers, a water displacement procedure was used. A 25 ml graduate was filled to the 15 ml point and the specimens were then placed inside. The new water line was recorded with the difference being the amount of volume of the material. This would indicate absorption of the solution or loss of material to solution during the tests. Upon removal from the chemical tests, a close visual examination of the specimens revealed any cracks or changes in flexibility.

Specimens of the gasket material presently being used in commercial pipe joints were also tested using this procedure. Each was weighed and sized in the same manner as the HST. Both the HST specimens and the commercial gasket materials were subjected to the chemical tests for 1000 hours each. The results of the second Chemical Resistance Tests are presented in Figures 11 - 17.

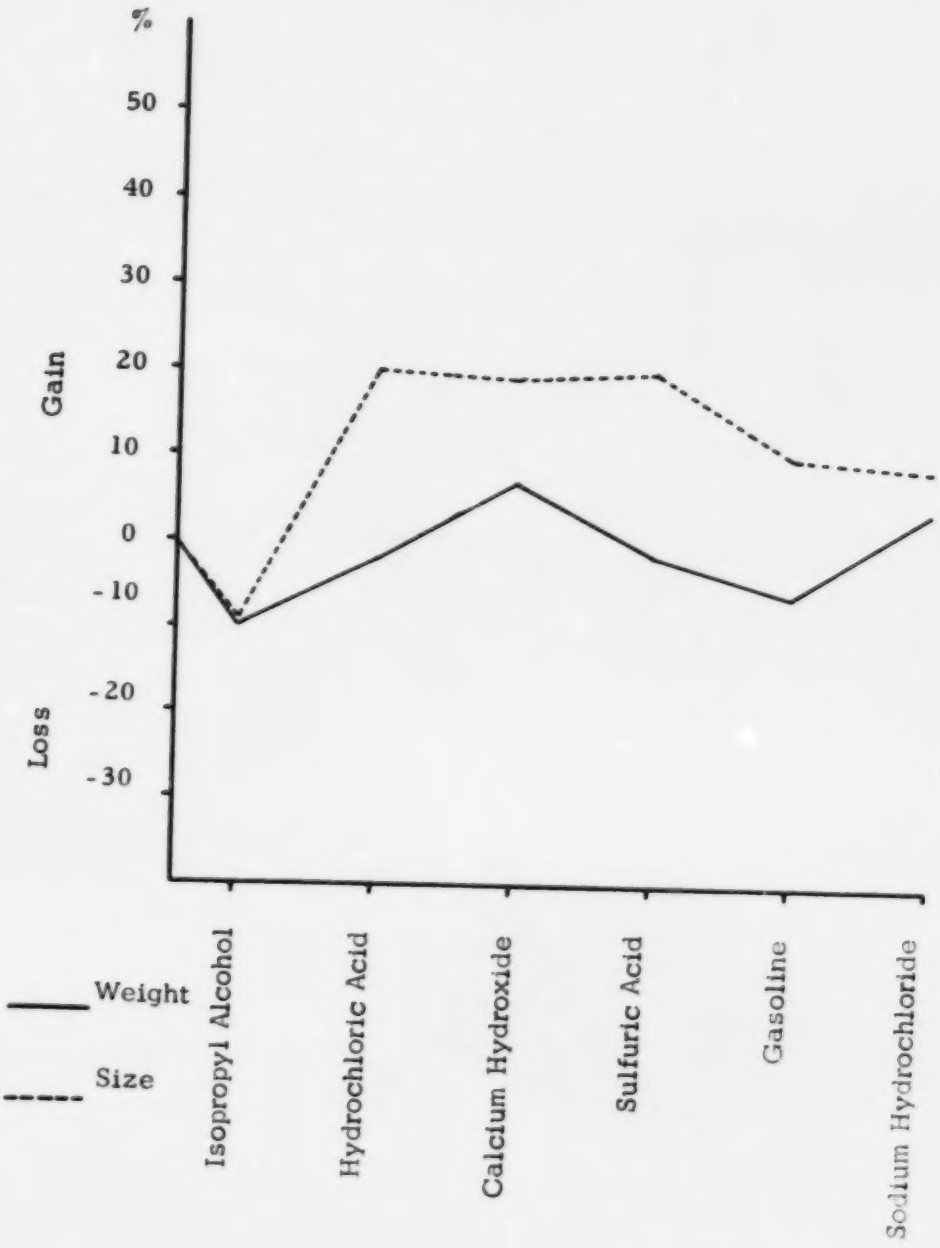


Figure 11. Clay Bell and Spigot Joint Chemical Resistance Test Results

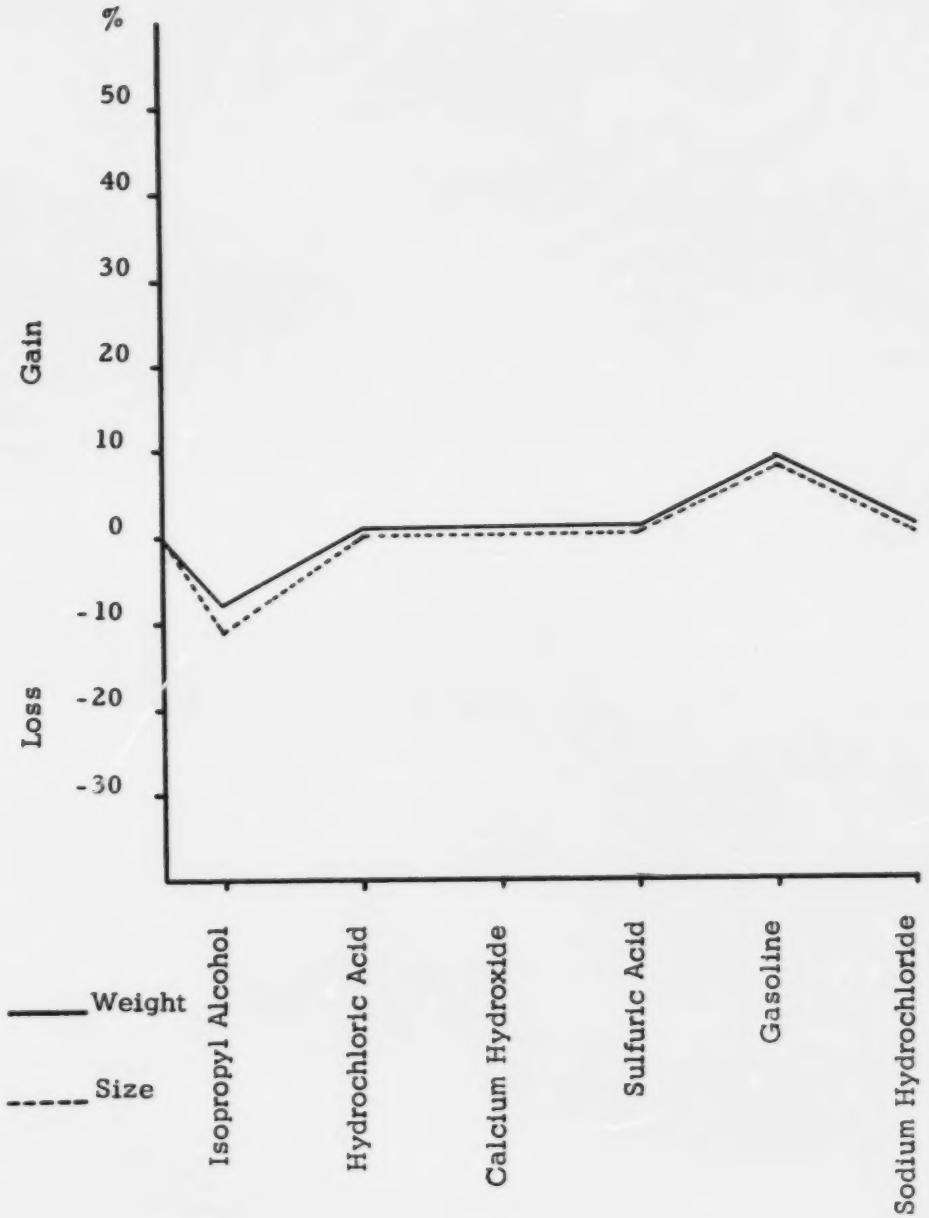


Figure 12. Concrete Bell and Spigot Joint Chemical Resistance Test Results

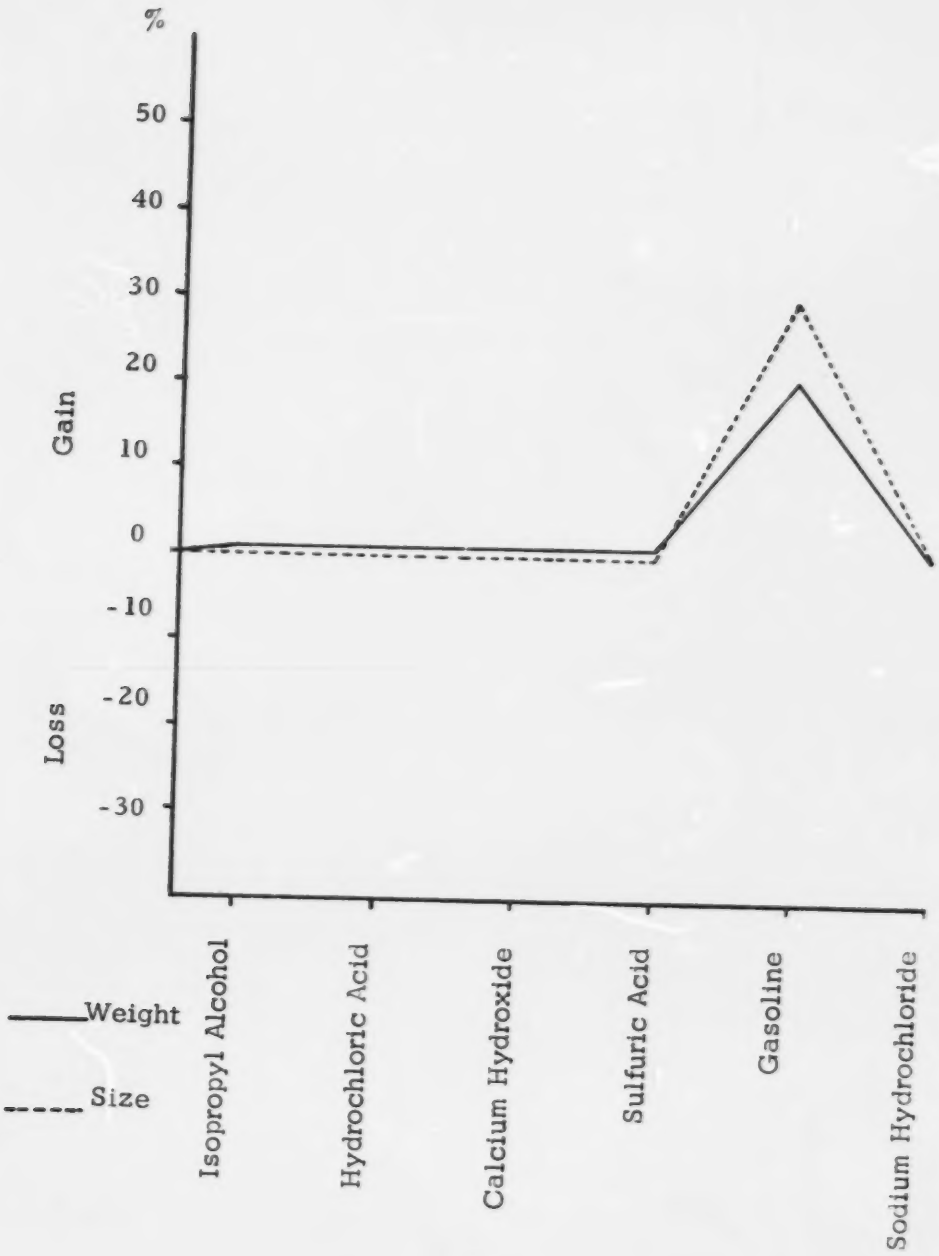


Figure 13. Asbestos-Cement Joint Chemical Resistance Test Results

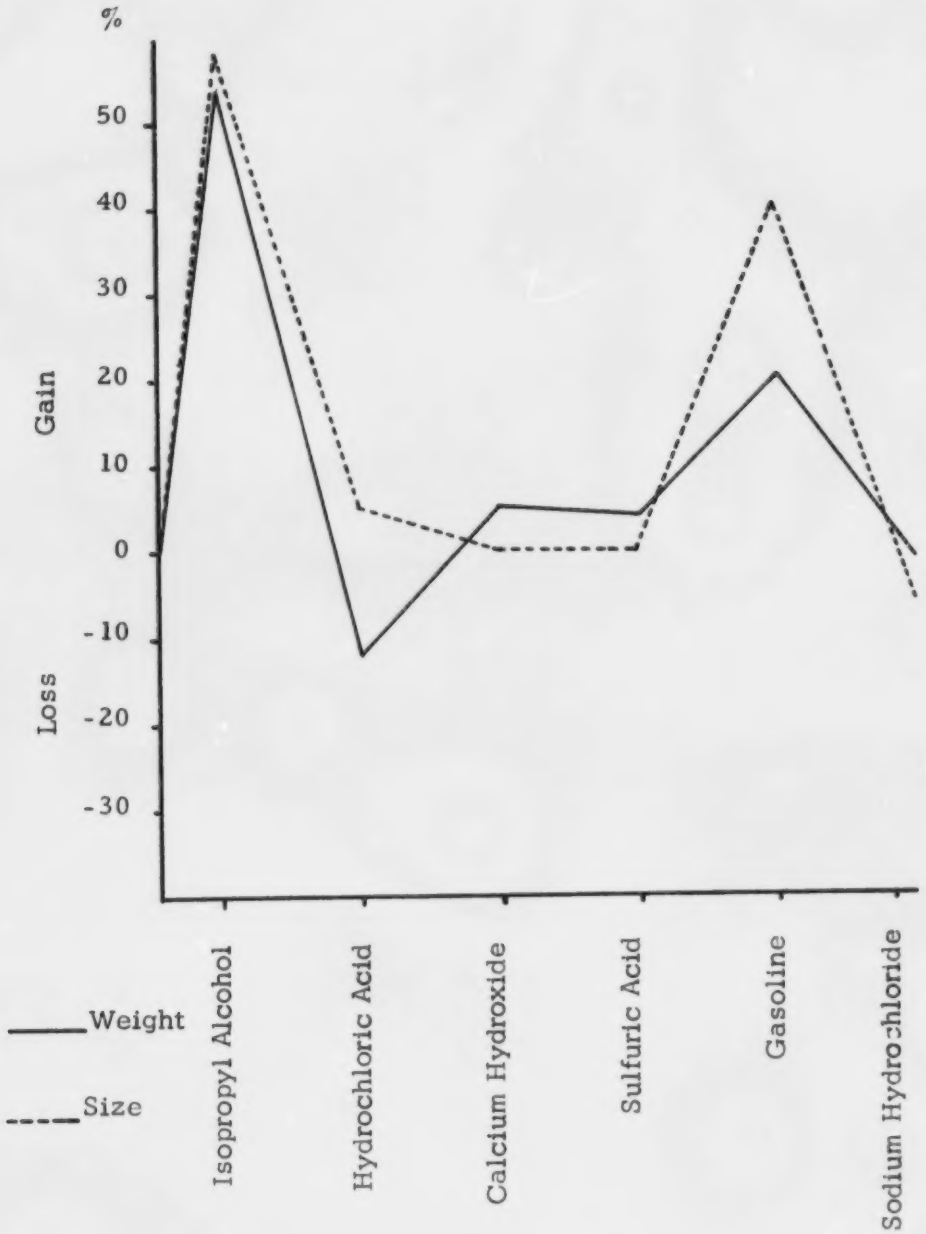


Figure 14. Clay Compression Coupling Chemical Resistance Test Results

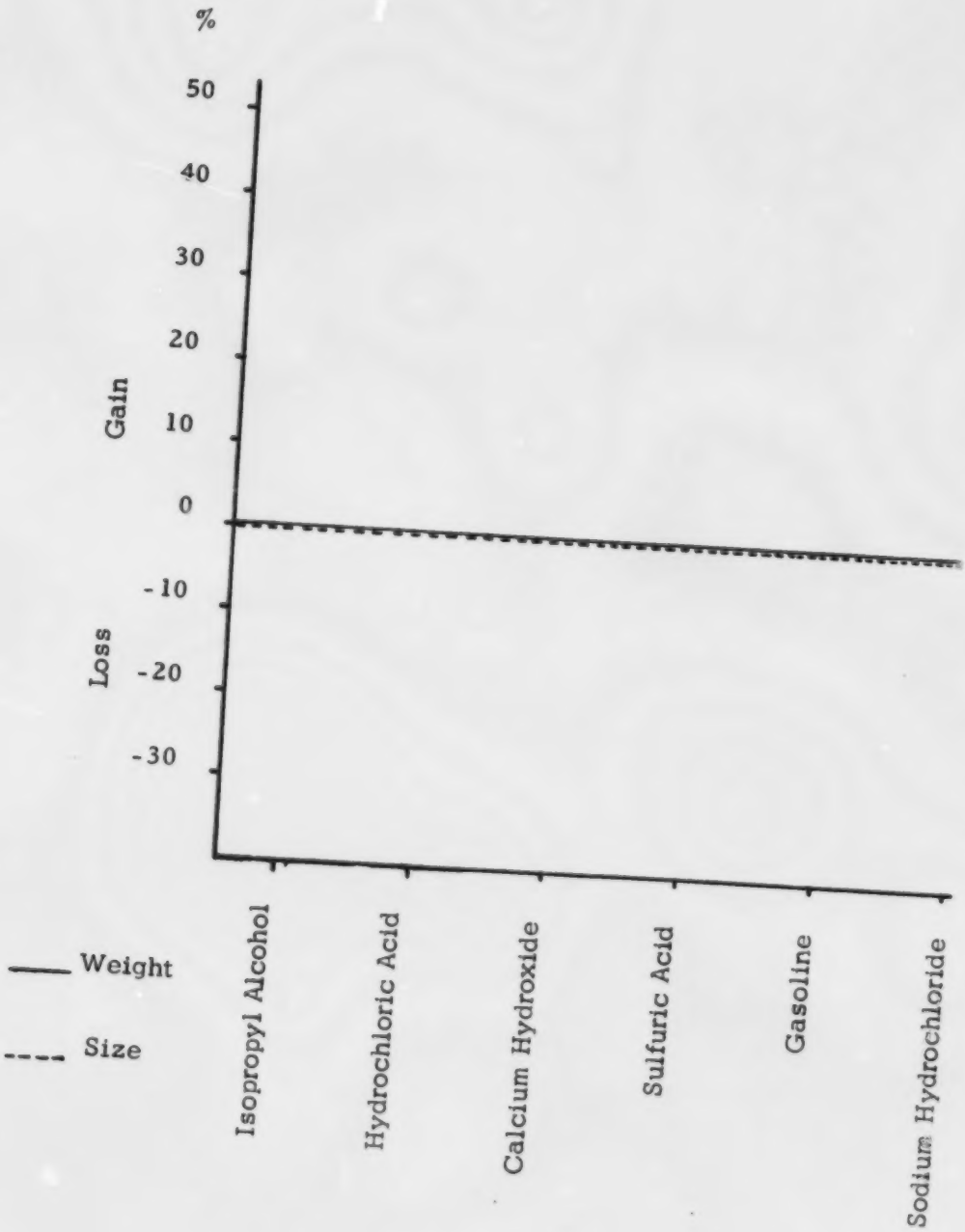


Figure 15. FEP Teflon HST Chemical Resistance Test Results

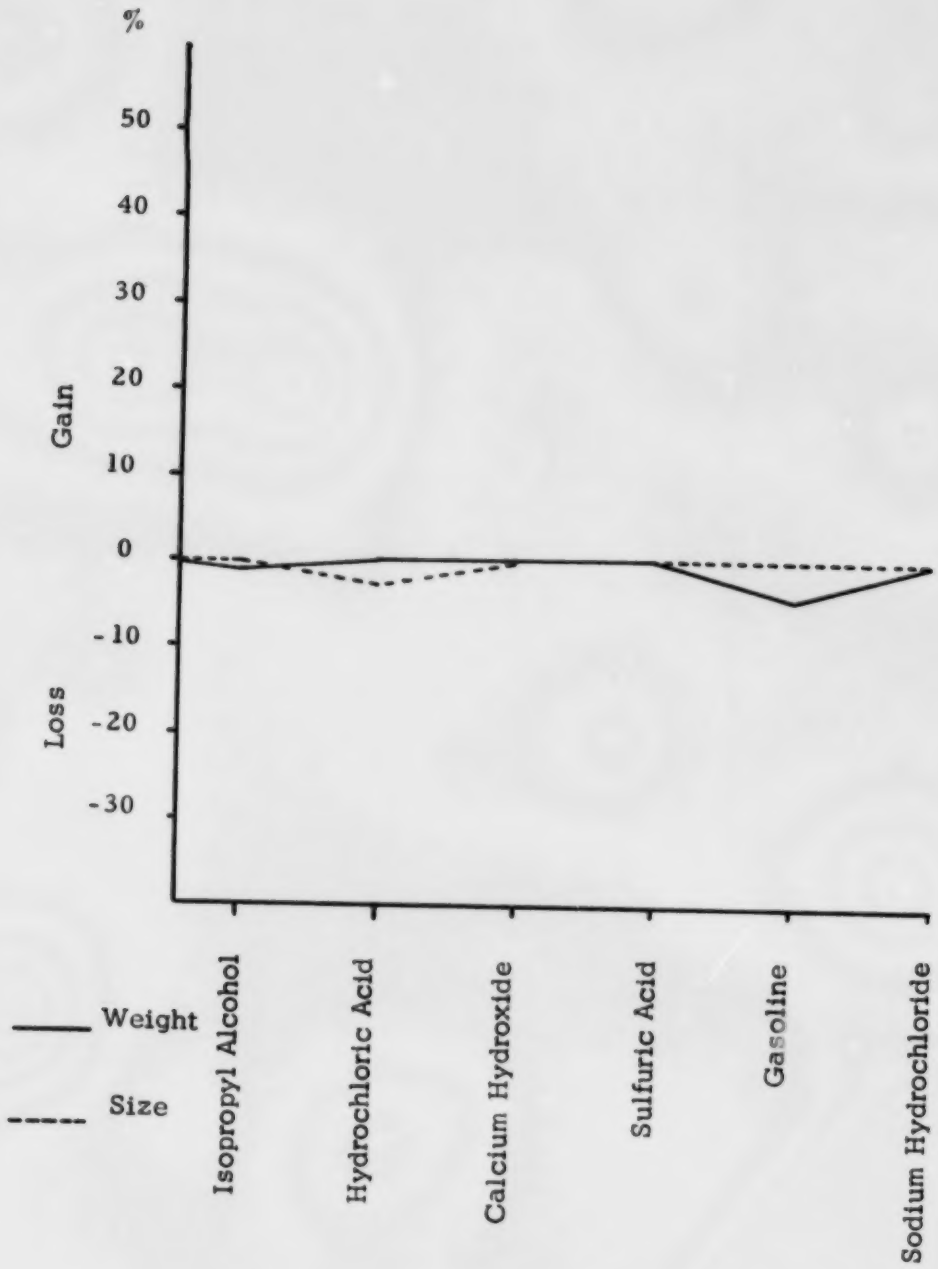


Figure 16. Polyolefin HST Chemical Resistance Test Results

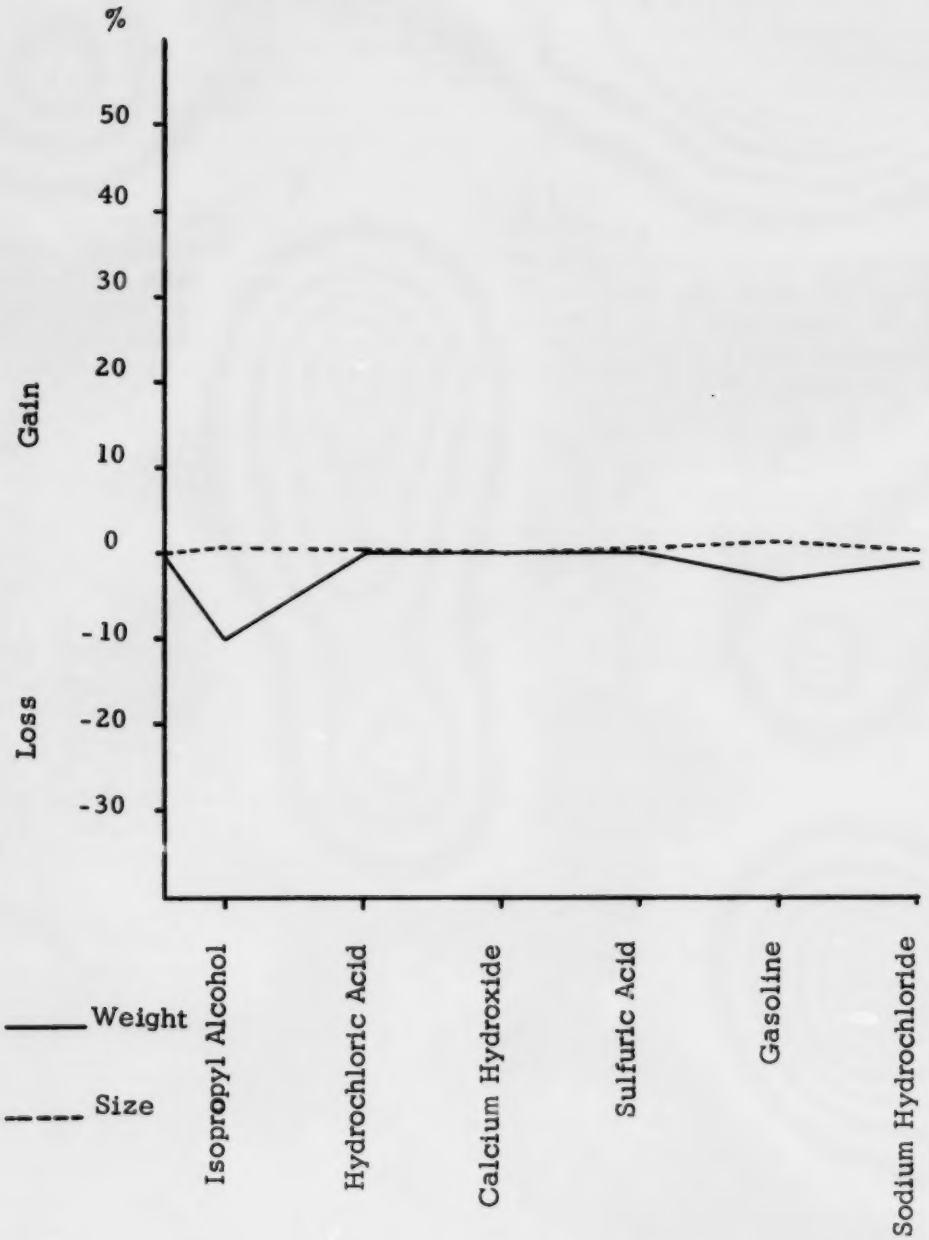


Figure 17. Polyvinyl Chloride Chemical Resistance Test Results

The gasket material used with clay bell and spigot pipe turned the isopropyl alcohol yellow, while the specimen exposed to the sodium hypochloride was covered with small hairline cracks. The concrete bell and spigot gasket material also developed cracks from exposure to the sodium hypochloride, but turned the isopropyl alcohol red as did the asbestos-cement gasket material. The latter showed no other signs of wear.

The clay pipe compression coupling showed the largest degree of change after the chemical resistance tests. The specimen in isopropyl alcohol gained 15/16 inch in length. The gasoline specimen gained 7/8 inch in length. The specimen placed in the sodium hypochloride turned the solution a cloudy gray and displayed signs of dissolving in the bleach. The submerged half of the specimen was sticky and easily scraped away.

The HST materials generally performed well in the chemical resistance tests with the exception of hydrocarbon solutions. Of these, two exhibited a weight loss. The FEP Teflons displayed excellent chemical resistance.

Adhesives

Recognizing the sealing and bonding improvements an adhesive might impart to the HST joint, tests of three available adhesives were conducted during Phase I testing. Two of these were found to be available on polyethylene tubing.

The first polyethylene HST had a petroleum base adhesive which remained soft and sticky after cooling and separated from the contact surface under relatively low pressure. It was also easily dissolved by hydrocarbon solution.

The second type consisted of an irradiated polyethylene HST with a non-irradiated polyethylene liner. With heat applied, the tube shrinks and the inner liner melts to form a snug watertight seal. The chemical resistance tests, however, indicated that this adhesive would be unsatisfactory for use in a sewage system.

The third adhesive tested was a butyl adhesive tape sealant. A strip of the tape was wrapped around the end of each pipe at the joint and the HST recovered around it. The physical properties tests indicated it would form a strong waterproof joint, however, the tape was highly soluble in gasoline and oil. The results of the chemical tests for these materials are as shown in Figures 18 - 20.

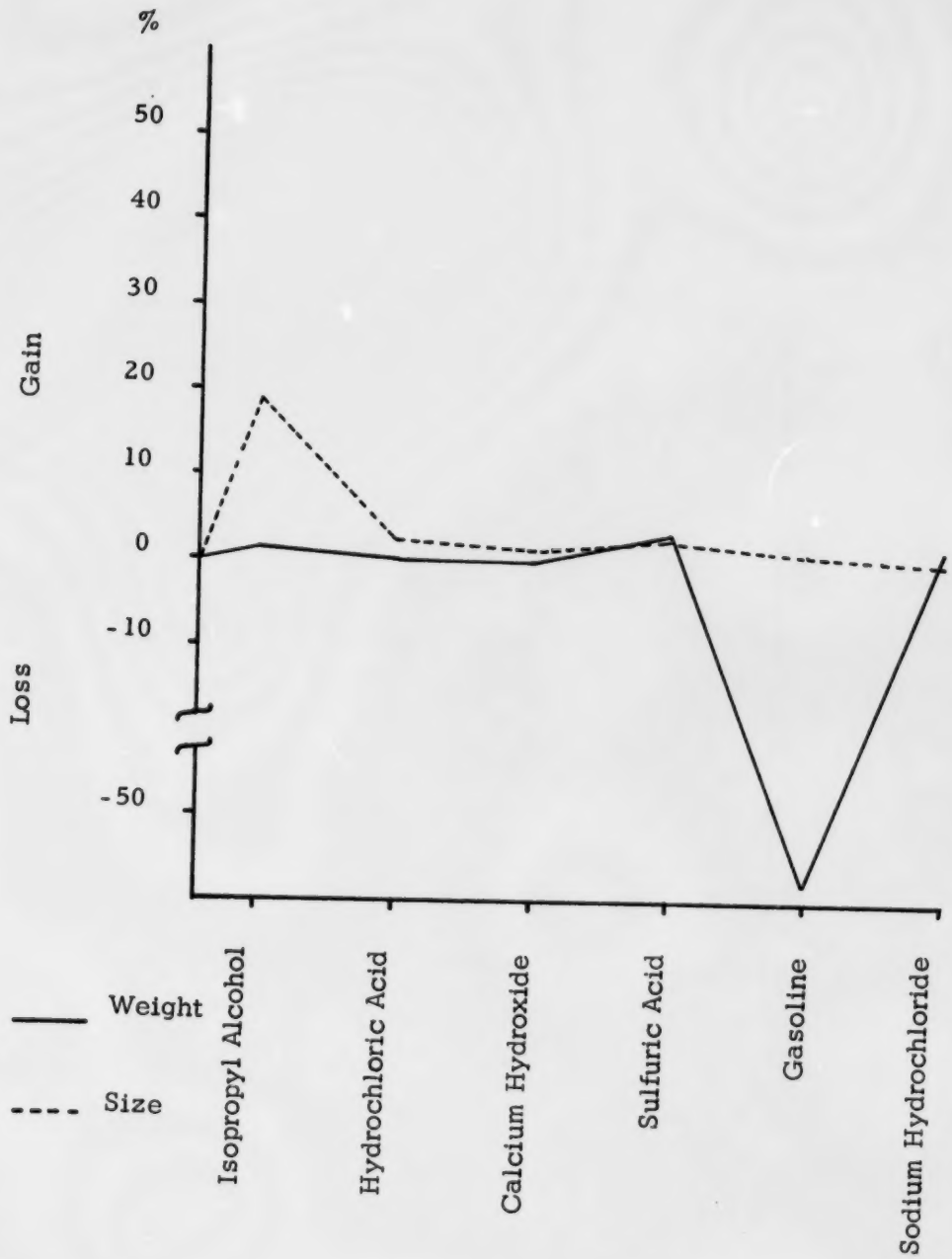


Figure 18. TPS 1000 Polyethylene with Adhesive Chemical Resistance Test Results

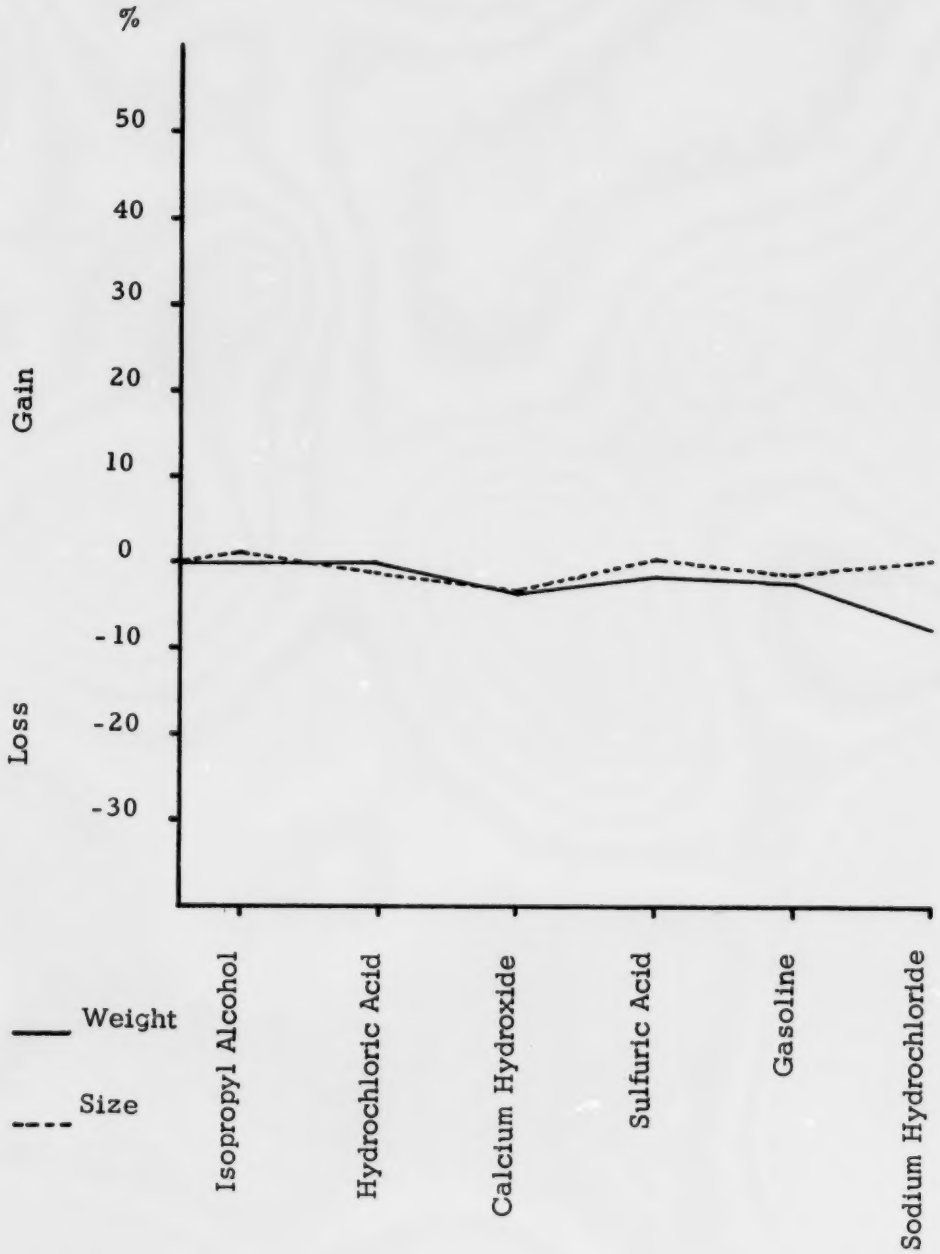


Figure 19. WRS Polyethylene with Adhesive Chemical Resistance Test Results

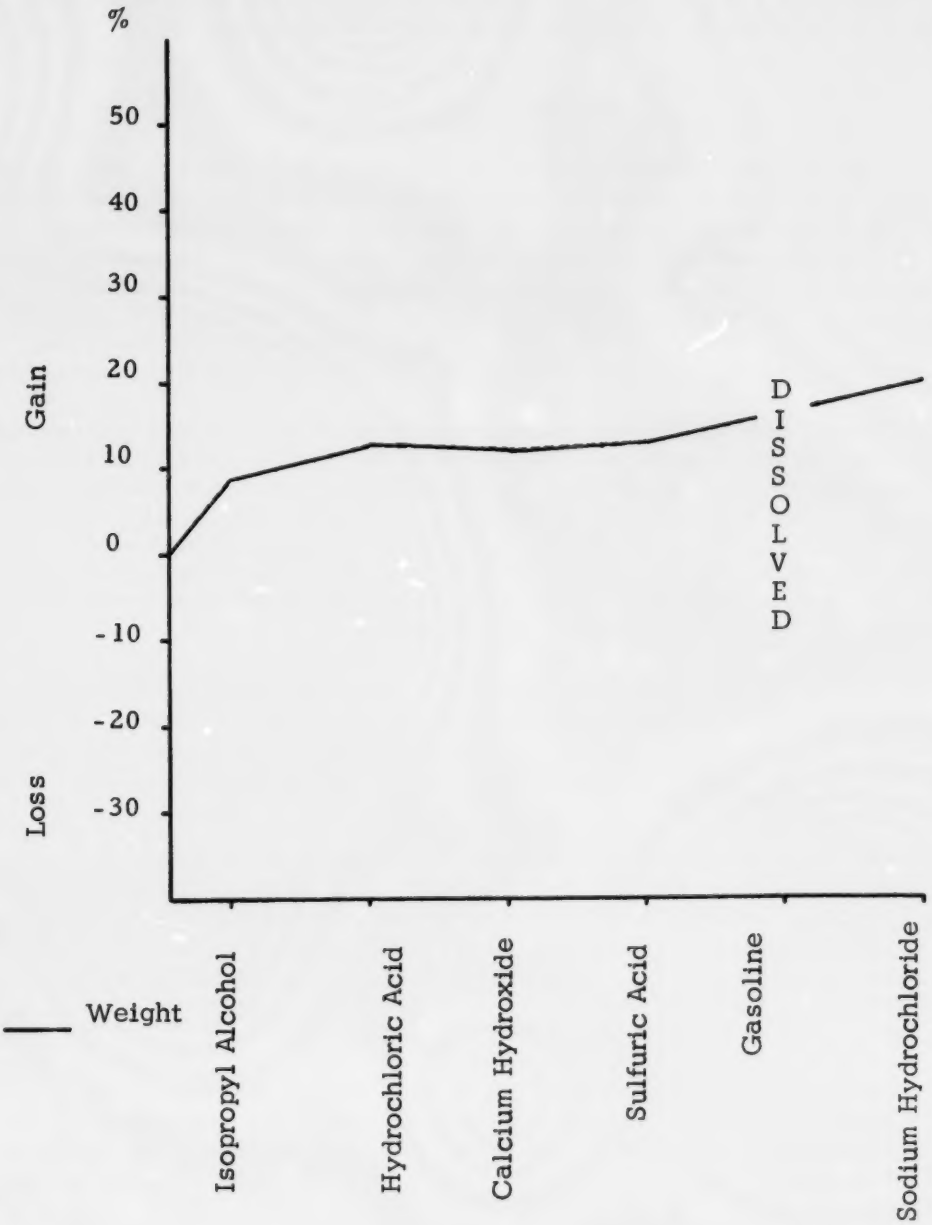


Figure 20. Butyl Adhesive Tape Chemicals Resistance Test Results

As a result of these tests, the search for additional adhesives was continued in an attempt to identify more suitable products.

Materials Selection

At the completion of Phase I testing had been conducted on twelve types of HST. Forty-one manufacturers and distributors had been consulted on the possibilities of using various types of HST in a sewer system, and an extensive literature search had been conducted to develop as much information as possible about the technology of heat shrinkable tubing. Visits were made to the manufacturers of clay, concrete and asbestos-cement pipe to develop their interest in the program, and to gather additional information on adapting HST materials to use in a sewer system.

The Phase I activities were designed primarily to evaluate the use of HST materials as a sewer pipe joint. At the end of this phase, it was concluded that the use of HST as a material and method for joining sewer pipe was a reasonable and practical approach to eliminating infiltration of groundwater and exfiltration of sewage through a joint source. The HST products which responded to heat quickly, recovered uniformly, and had immunity to chemical and bacterial attack were considered as candidates for the full scale tests of Phase II.

After comparing the test results of HST with and without adhesives, it appeared that the addition of heat activated adhesive would add considerable strength to the joint. The adhesive would fill any flow channels created on the rough porous surface of the sewer pipe and still retain the flexibility of the HST.

The HST materials considered for Phase II were polyolefin, FEP teflon, polyvinyl chloride (PVC), silicon rubber, and viton. The FEP teflons were chosen for their high thermal pressure test results and resistance to chemical attack. This material is very expensive, but if it could be manufactured on a large scale, indications were the price would drop sharply. It responded very quickly to hot air and gas torch heating devices, and had a high degree of flexibility.

The polyolefin heat shrinkable tubing also responded quickly to various heat sources and was highly resistant to scorching and burning. This feature makes it easy for a man under pressure of time to slap these joints together. It has a high degree of chemical resistance and resists cutting and punctures after shrinkage. After consulting the manufacturer, it was found that this material in the 8 inch recovered size could be marketed at less than $2.00 per foot on a large volume basis. Considering the test results, economics, and ease of application, this material was chosen for Phase II.

The physical property test results on the polyvinyl chloride HST were not very impressive. After debating the test results of Phase I, it was decided that a smaller recovered diameter would have given a tighter fit on the simulated sewer pipe. The pipes were 1.2 inch in diameter and the manufacturer listed the recovered diameter of the HST at 1 inch. If the recovered diameter of the HST had been smaller (3/4 in.) a tighter seal would have been obtained. Unfortunately, a smaller recovered diameter is available only in a smaller expanded diameter which would not fit the pipe. These diameter discrepancies could be corrected by the manufacturer for economic order sizes. The PVC tubing did recover uniformly and have the chemical resistance necessary. It was felt that it would work in Phase II particularly if used with an adhesive.

The fourth HST material considered for Phase II was silicon rubber. It had a good chemical resistance to all chemicals except for high concentrations of hydrocarbons, such as gasoline and alcohol. Since there are often strong solvents in industrial sewage, this material was not carried into Phase II. In addition, an 8 inch recovered diameter tubing is not manufactured at this time, which would have further complicated testing arrangements.

The viton HST had the highest shear resistance of any HST material without an adhesive. It withstood 460 lbs. shear load, 15 psi internal pressure, and had a hoop pressure of 62 psi. The chemical resistance test results were a very low percentage (less than 9%), and the material recovered easily under moderate heat. The cost of this material was the only weak point. After consulting the manufacturer, it was found that the cost of this material could not be lowered to within a price range that would make it practical for large scale sewer installation. Raw polyolefin compounds used to make HST cost the manufacturer approximately $.25 per pound. The raw viton compounds cost the manufacturer approximately $11.00 per pound. This would make the viton 44 times more expensive before extrusion and other manufacturing costs.

SECTION VII

FULL SCALE TESTING

Test Procedures

All of the joints, both commercial and HST, were made using 8 inch diameter commercial sewer pipe. The three types of pipe used were clay, concrete, and asbestos-cement. A reference in this report to a "concrete joint" will be to a joint assembled using commercial concrete pipes and the bell and spigot joint assembly supplied with it. A reference to a "concrete HST joint" will be to a joint using plain-end sections of concrete pipe and heat shrinkable tubing. This terminology will also apply to the clay and composition (asbestos-cement) pipe as well.

The full scale laboratory physical property tests involved testing each type of commercial joint under the ASTM procedures for that specific joint, and then increasing the loads and pressures on the joint until leakage occurred. An additional test for tensile strength of the joint, for which there is no ASTM specification, was also conducted. Upon completion of the commercial joint tests, a second series of tests was conducted on HST joints following the same procedures as used on the commercial joints.

Since the change in size from 1 inch to 8 inch diameter would not change the chemical resistance or thermal (hoop) pressure of the HST material, these tests were not incorporated into Phase II full scale testing. Four different physical strength tests were conducted. Tensile, shear, internal pressure, and deflected internal pressure tests were used.

Test Facilities

The test stand for 8 inch sewer pipe was designed to allow all testing to be conducted with one piece of multi-purpose equipment. Provisions for the internal pressure tests, deflected internal pressure tests, shear tests, and tensile tests were incorporated in the stand which is depicted in Figure 21. The pipes could be mounted horizontally for the internal pressure test. One end of the joint could be elevated upon completion of the internal pressure test for the deflected internal pressure test. The frame-work supporting one pipe could be lowered and a hydraulic jack mounted above the pipe to conduct the shear test. One of the pipes could be mounted on rollers and connected to the tensile-pull apparatus for the tensile test. This equipment was used for all full scale testing.

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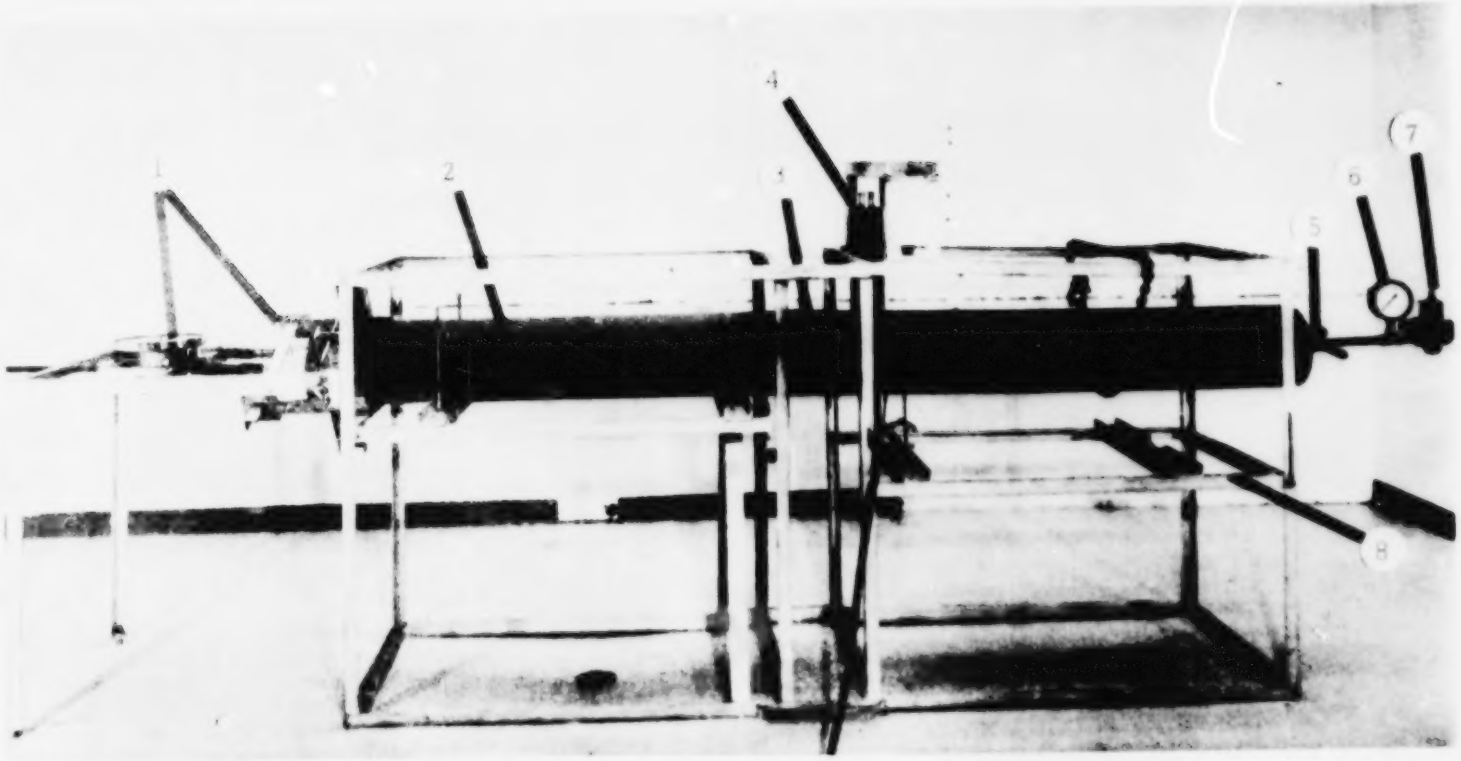

1. Tension Apparatus
2. Plain-End Pipe
3. HST Joint
4. Hydraulic Shear Jack
5. Expandable Packer
6. Water Pressure Gauge
7. 0-15 psi Regulator
8. Retractable Pipe Support

Figure 21. Full Scale Test Apparatus

Internal and Deflected Internal Pressure Tests

In conducting the internal pressure and deflected internal pressure tests, the joint was assembled and pipe plugs were placed in the open ends of the pipe. The pipes were then chained together to prevent their separation by hydrostatic pressure, and filled with water. Following the specifications in the ASTM for each particular joint, the internal pressure was maintained for the prescribed length of time. Upon completion of this test the pressure was increased at the rate of 1 psi per minute until the joint leaked or the pressure reached a maximum of 15 psi. The psi maximum resulted from the amount of pressure the pipe plugs could withstand without leaking. If the joint failed the internal pressure test, a new joint assembly was used to conduct the deflected internal pressure test. Three specimens of each joint were subjected to each test using this procedure.

Shear Test

The only requirements for a shear test were incorporated into the clay plain-end and clay bell and spigot pipe ASTM. Inspection of the ASTM for concrete rubber gasket joints and asbestos-cement joints revealed that there is no shear test for these two types of joints. In order to maintain uniformity in testing, shear tests were conducted on these joints following the ASTM requirements for "Compression Joints for Vitrified Clay Bell and Spigot Pipe", C425-66T.

Tensile Test

The tensile test was included in the program because of various connections in a sewer line which might tend to drop or separate, such as house-laterals and elbows. In establishing a procedure for the tensile test, the test apparatus was modified to allow one pipe to rest on rollers to reduce the friction produced by the pipe weight opposing the applied tensile force. The other pipe was mounted stationary on the pipe rack and tension was applied until the joint separated. At the point of separation, the highest reading on the dynamometer was noted. Application of tensile force was continued until that necessary to pull the pipe along the rollers was determined. To determine the actual tensile force necessary to separate the joint, the force needed to pull the pipe was subtracted from the amount of force used to separate the pipe joint. The tensile test was limited to 900 pounds due to the strength of the sewer pipes. When the test apparatus was attached to the pipe tight enough to surpass 900 pounds of tension the pipe would crack or break in compression.

Heat Source

A propane torch, Raychem Model FH-2606,[8] was used to heat all of the HST joints during the full-scale testing. The torch flame was a soft yellow-orange and could be adjusted to varying temperatures.

Materials Tested

During the full scale laboratory testing, tests were conducted on clay bell and spigot pipe with a rubber gasket, concrete bell and spigot pipe with a rubber "O" ring, asbestos-cement pipe with rubber gaskets, and plain-end clay pipe with compression couplings. The HST joints were tested in conjunction with sections of clay, concrete, and asbestos-cement plain-end pipe. All testing was accomplished under uniform conditions following the procedures previously outlined. A complete listing of all materials used in the testing is included in Appendix D.

To directly compare the performance of HST joints and conventional joints on 8 inch commercial pipe, the test results shown in Figures 22 - 25 are grouped for all joints tested by type of test. Actual test results for each joint are tabulated in Appendix E.

Conventional Joint Test

Of the three types of commercial joints tested, the asbestos-cement performed the best. It was tested according to the procedures and requirements as outlined in ASTM, C427-69a, "Asbestos-Cement Nonpressure Sewer Pipe". Three joints were subjected to each test. Since the joint and the pipe are separate pieces, only the collar was replaced if the joint leaked. None of the asbestos-cement joints failed the physical property tests. Test results for this joint are given in Appendix E, Table 1.

It was noted that the lubricant used to join the pipes could easily pick up dirt and debris during installation, which might cause joint leakage. Also, the asbestos-cement pipe barrels did not sweat or seep water from the hydrostatic pressure as did the clay and concrete pipe.

The clay bell and spigot pipe joints were tested following the specifications of ASTM C425-66T, "Compression Joints for Vitrified Clay Bell and Spigot Pipe." Heavy sweating was noticed on the pipe barrels while under pressure. The specifications require a hydrostatic pressure of 4.3 psi for one hour. All joints passed the ASTM requirements. Test results for this joint are given in Appendix E, Table 2.

The concrete pipe with rubber gaskets was not as successful as the other two types of pipe and joints. It was tested following the procedures outlined in ASTM, C433-70, "Joints for Circular Concrete Sewer and Culvert Pipe, Using Rubber Gaskets". Two of the three joints of this type met and surpassed the ASTM requirements. The third joint leaked during the internal pressure test. The joint was disassembled and checked for cracks or debris in the joint, and reassembled with a new rubber gasket. The deflected internal pressure test was then conducted on this joint. Leakage occurred at a pressure less than 10 psi. The joint was disassembled, cleaned, and reassembled with another new rubber gasket for the shear test. The joint withstood the internal pressure of 10 psi until the shear load was applied, at which point it failed again. The concrete pipe also experienced heavy sweating and pin-head squirts of water sprayed two to three inches out from the barrel of the pipe. The results of these tests are tabulated in Appendix E, Table 3.

The ASTM, C584-66T, "Compression Couplings for Vitrified Clay Plain-End Pipe", stipulates that a coupling shall be fabricated with a stop ring which serves to properly position the pipe in the coupling and which acts as a cushion between the mating ends of the pipe". This stop ring, which prevents chipping and cracking of the ends of the pipe, was not provided in the couplings purchased for testing. When purchasing this type of joint it should be stipulated that the ring be included to insure longevity of the sewer system. Test results are given in Appendix E, Table 4. The compression coupling joint did not appear to have as much physical strength or chemical resistance (Figure 14) as some of the other joints tested, but it did possess a high-degree of flexibility. The bell-less design of this system would ease installation and trenching, but the cost of the joint mechanism is high in comparison to the other types of joints tested.

Heat Shrinkable Tubing Test

To provide a significant incentive for adaption and use within the sewer industry, it was recognized that the HST joints should surpass the performance requirements of the conventional joint systems. After evaluating the ASTM specifications for joints and the conventional test results the following requirements were established for testing of the HST joints:

1. Withstand without leakage a hydrostatic pressure of 10 psi for one hour in straight alignment.

2. Withstand without leakage a hydrostatic pressure of 10 psi for one hour when deflected 1/2 inch per foot of pipe length.

3. Withstand, without leakage, a hydrostatic pressure of 10 psi for one hour with a shear load of 150 pounds per inch of nominal diameter applied over an arc of not less than 120 degrees and along a longitudinal distance of 12 inches.

4. Have a tensile strength of at least 376 pounds, twice that developed by the conventional joints.

Heat shrinkable tubing with a recovered diameter of 8 inches or smaller and an expanded diameter of 11 inches or greater was not readily available. Discussions with various HST manufacturers stimulated their interest in the program and resulted in the procurement of 8 inch recovered polyolefin and FEP teflon HST at nominal charges. As a market for 8 inch heat shrinkable polyvinyl chloride tubing had not previously been established, this material was not available. Rally Industries of California undertook to supply the 8 inch PVC tubing for the cost of set up and tooling expenses. Hence, the program was limited to testing polyolefin, FEP teflon, and polyvinyl chloride (PVC) HST materials during Phase II.

The initial full scale tests of 8 inch HST joints in conjunction with plain-end commercial sewer pipes identified some serious problems. It was found that none of the HST joints gave a shrink fit tight enough to fill the depressions and minute grooves on the outer surface of the three types of sewer pipe. Leakage did not occur with the 1 inch diameter pipe in Phase I due to the smooth surface contact between the HST and glazed pipe. Flow channels which resulted from indentations and bumps on the outer surface of the sewer pipe were easily distinguished when hydrostatic pressure was increased. Experiments were conducted using "O" rings and various gasket combinations to eliminate the problems, but these were generally found to be unsuitable solutions.

At the conclusion of small scale testing, the search for a suitable hot melt adhesive material had been continued. These materials were felt to offer the greatest adaptability to the HST sealing need. They will flow when melted to seal the indentations and bumps, and are generally economical. As a result of the continuing search, several important characteristics of the adhesive were identified. The two most important factors involved in a marriage between the HST pipe joint and a hot melt adhesive are chemical resistance and flow temperature. The flow temperature of a hot melt adhesive is the temperature at which the adhesive turns from a solid to a semi-liquid. At this point, the adhesive begins to flow and fill any depressions or cracks. To insure that the adhesive is completely melted, the flow temperature should be lower than the shrink temperature of the HST joint. The chemical resistance of the hot melt adhesive must also exceed the strength of any chemicals that are found in a sanitary sewer system.

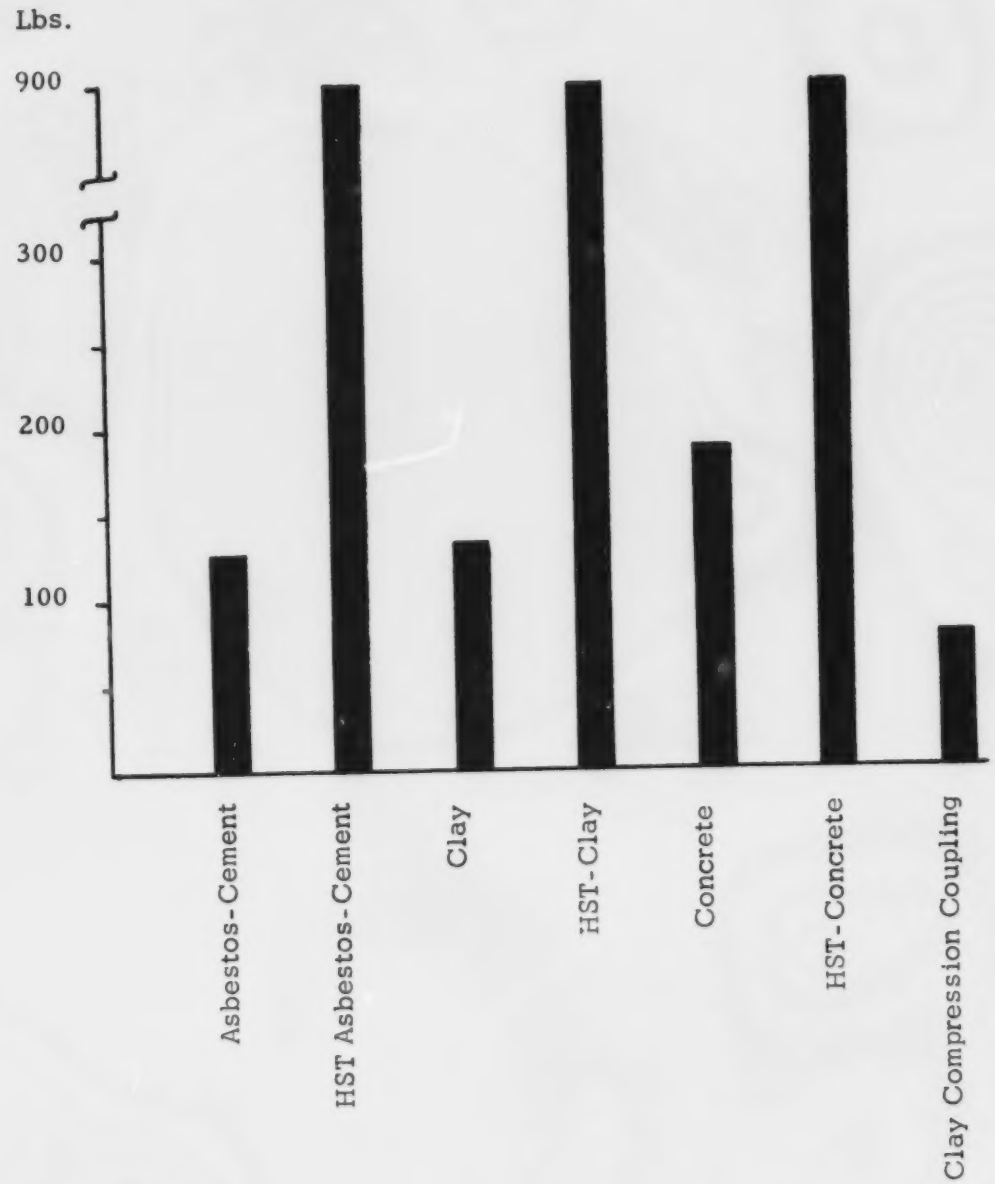

Figure 22: Full Scale Tensile Test Results

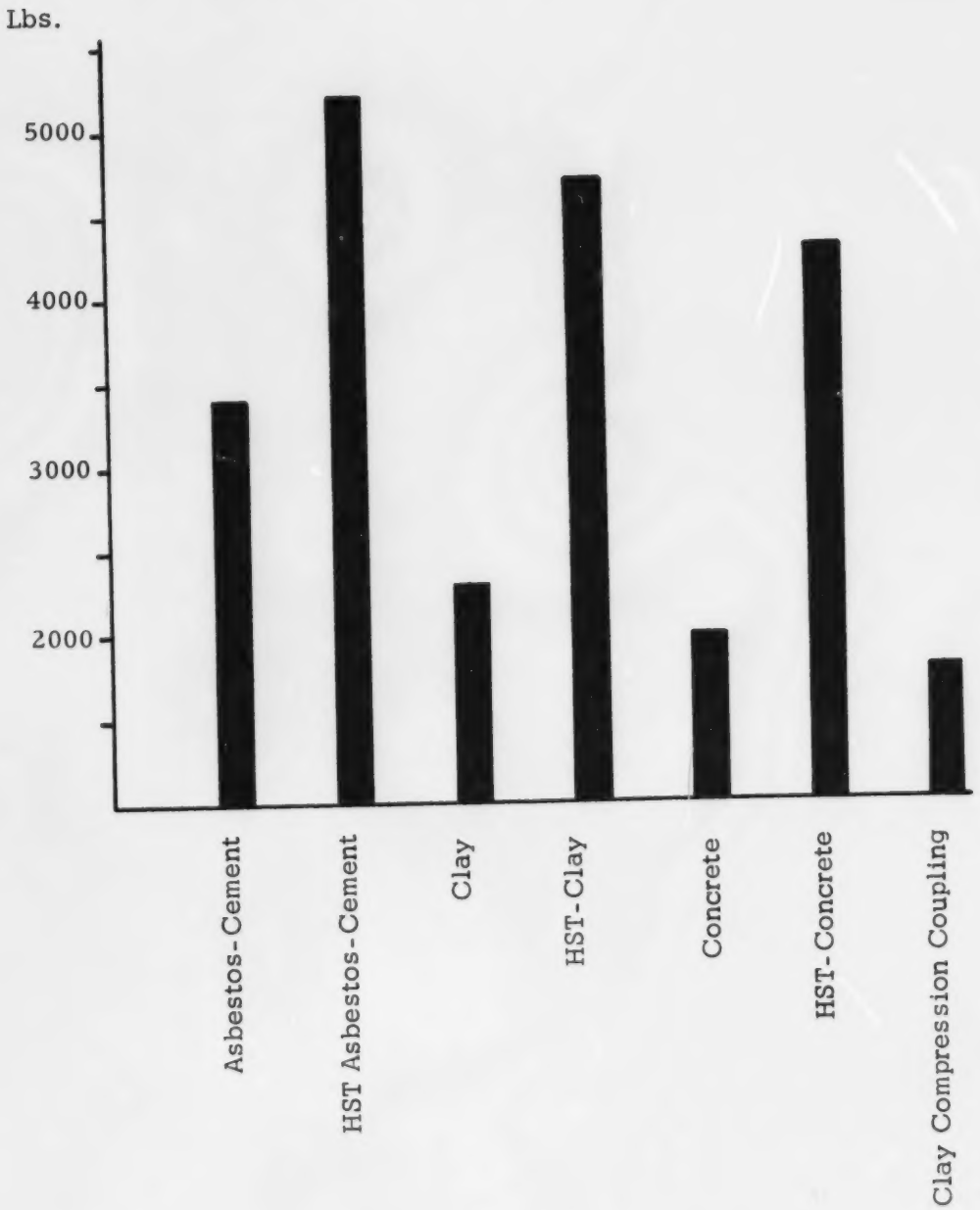

Figure 23: Full Scale Shear Test Results

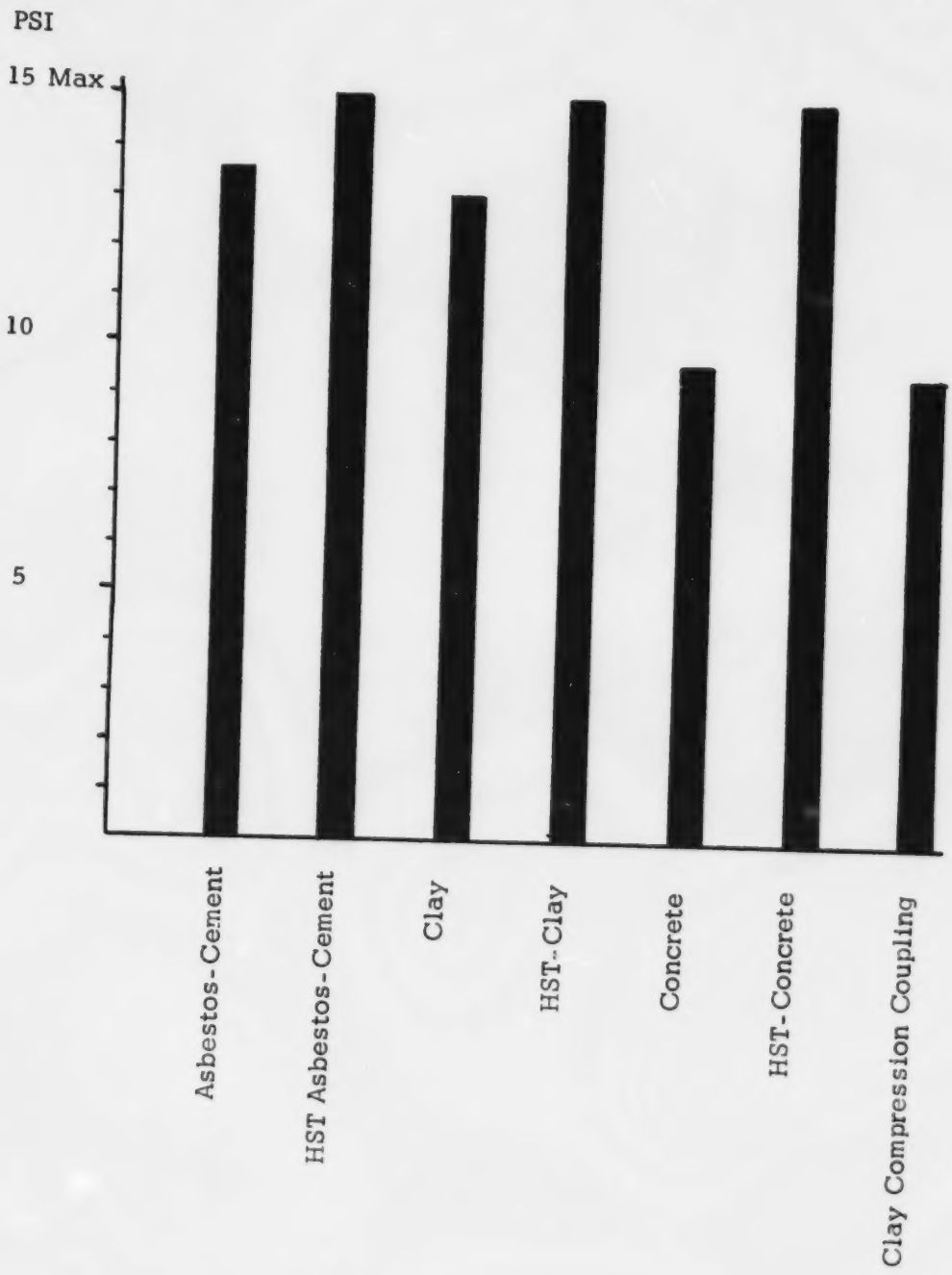

Figure 24: Full Scale Internal Pressure Test Results

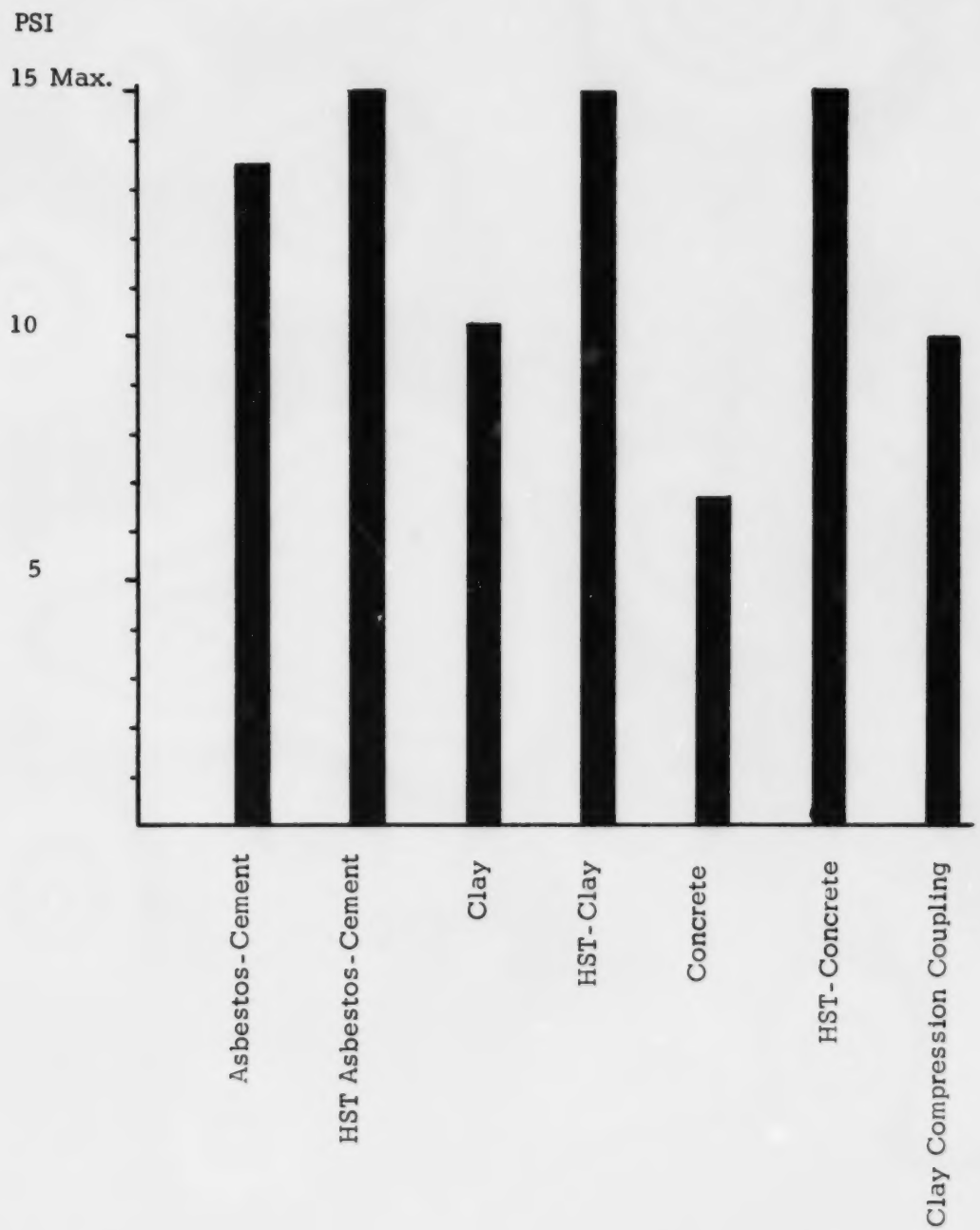

Figure 25: Full Scale Deflected Internal Pressure Test Results

The two above factors combined create a problem. As the flow temperature of the hot melt adhesive is lowered, so is the chemical resistance. In attempting to match a low flow temperature and a high degree of chemical resistance, over 20 adhesive manufacturers were consulted. Of the adhesives received and tested, most exhibited more than sufficient strength to pass the physical property tests. None of these materials, however, could withstand strong hydrocarbons such as 100% concentrations of gasoline and alcohol. As this concentration was severe and highly unlikely in a sewer system, those adhesives with the most suitable chemical characteristics were subjected to the physical property tests.

The hot melt adhesive which displayed the most favorable overall characteristics with the HST materials in Phase II was the CC150 by Stuck Adhesives. This was subjected to the physical property tests in conjunction with polyolefin, FEP teflon, and PVC heat shrinkable tubing on clay, asbestos-cement, and concrete pipe. This adhesive is a polymeric type with a flow temperature of 350^{o}F. It had a good chemical resistance to all chemicals except for high concentrations of gasoline and alcohol as shown in Figure 26. The CC150 has a 6 month storage life. The cost of the adhesive material for one joint would be less than $.25.

An investigation was also made into dry, heat activated epoxies. A heat activated epoxy with the same working characteristics as a hot melt adhesive would give a better chemical resistance. Several adhesive manufacturers and distributors were contacted for additional information on dry epoxies and resins. An epoxy which would react at a temperature between 200^{o}F and 500^{o}F in approximately three minutes could not be found.

Preliminary full scale tests were conducted on the HST joints with adhesives using 12 inch and 8 inch tubing lengths. It was found that there was no measurable loss of joint strength by reducing the length to 8 inches. As a result, 6 inch lengths were tested, however, uniform alignment on the pipe was difficult and would hamper ease of installation in actual use. In addition it was found that the 8 inch length of HST and adhesive resisted longitudinal movement from hydrostatic pressures. Chaining or otherwise securing the pipes during testing was not necessary as with conventional joints.

The series of photographs presented as Figures 27 - 29 demonstrate the process of assembling the HST joints tested. The joint shown was formed in an elapsed time of three minutes. A heat source which would encompass the joint heating uniformly would reduce recovery time to less than three minutes.

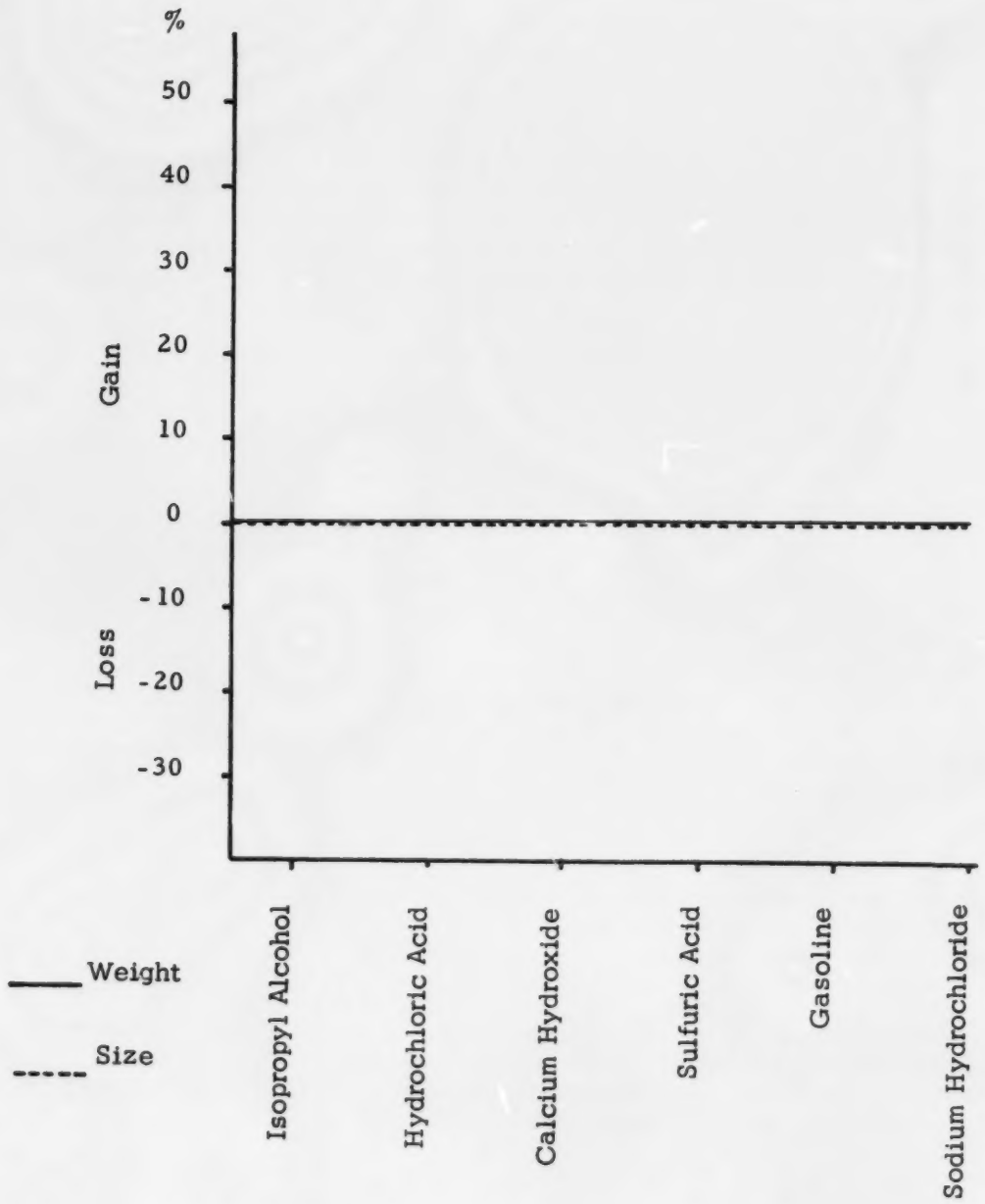

Figure 26. CC150 Hot Melt Adhesive Chemical Resistance Test Results

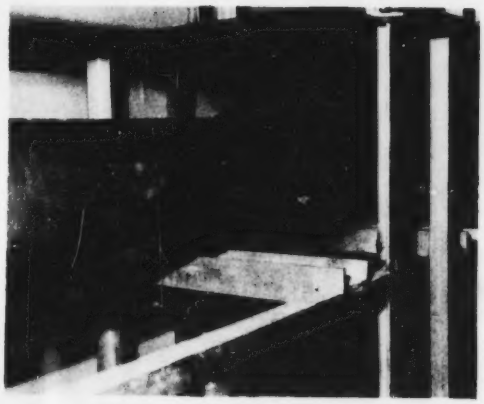

Figure 27. Placing the Heat Shrinkable Tubing Joint Around the Plain-End Pipe Joint

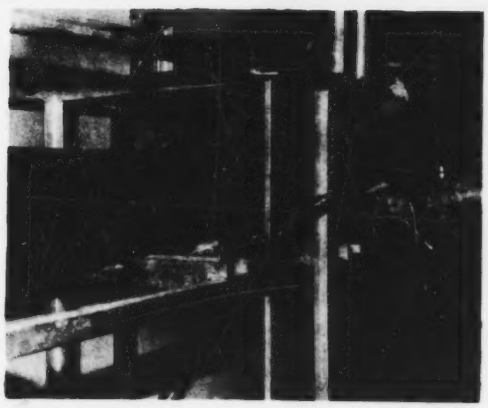

Figure 28. Heating the HST Joint With Gas Torch

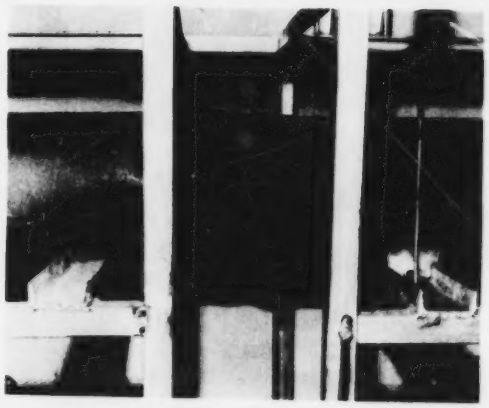

Figure 29. Completed HST Sewer Pipe Joint

The polyolefin HST bonded readily with the CC150. The polyolefin could withstand sufficient heat to allow the adhesive to completely melt and flow into the pores of the sewer pipe. This allowed a good bond to be formed with both the HST and the pipe. Results of the polyolefin tests are tabulated in Appendix V, Tables 5 - 7.

Since FEP teflon is basically a release agent, the hot melt adhesives would not adhere to it. The only adhesives which would bond with it were the gummy asphaltic base types. These adhesives were found unsuited for the application due to their lack of chemical resistance and low tensile strength. The manufacturer of FEP teflon responded with specimens of etched FEP teflon which also refused to adhere to the hot melts. If a suitable heat activated epoxy could be substituted for the hot melt adhesive, a bond could be obtained with this HST. Figure 30 shows a typical test and indicates that the FEP teflon is acceptable for joint use provided a suitable adhesive can be made available. Since adhesives which will bond to the teflon do not exhibit acceptable chemical resistance, testing was not pursued further and no test results are presented.

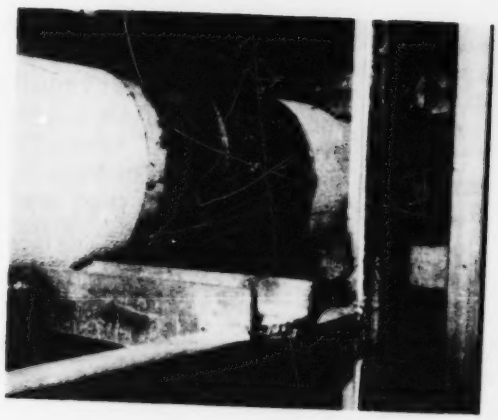

Figure 30. FEP Teflon Joint With Asphaltic Base Adhesive During Shear Test

As the polyvinyl chloride (PCV) HST was not available in a size appropriate for Phase II testing, it had to be specially manufactured for this program. Due to manufacturing difficulties the material was not received until the last month of testing. The tubing was formed from flat sheets which were wrapped and bonded to form a sleeve with the appropriate recovered diameter and wall thickness.

This tubing required a relatively low level of heat over an excessive time period (45 minutes) to melt the adhesive without ruining the tubing. This was felt to be impractical and heat resistance would have to be improved to make this tubing useable for sewer pipe joints. As a result of these observations, no tabulated data was obtained. Since heat shrinkable PVC tubing had not been manufactured in this size before, it was expected that some changes would have to be made in order to obtain a working product. Unfortunately, these changes could not be completed within the time constraints of the program.

The heat shrinkable tubing best suited for sewer joints appears to be the polyolefin. When used with a hot melt adhesive, the polyolefin HST joint is far superior to conventional pipe joints currently being used by the industry. The physical property test results presented in Appendix E and Figures 22 - 25 indicate the strengths that can be obtained using this material. The only failures from this system would result from an attack by strong hydrocarbon solutions on the hot melt adhesive.

Figure 31 shows the result of increasing shear load to 5700 pounds on plain end concrete pipe with this joint. There was no joint leakage at any time during the test. Figure 32 shows similar results obtained with clay pipe. The pipe broke under a load of 5300 pounds. Prior to breaking, there was no leakage from the joint. One additional test was performed on the clay pipe with a polyolefin adhesive joint. This test is depicted in Figure 33. The total load on the pipe was 995 pounds.

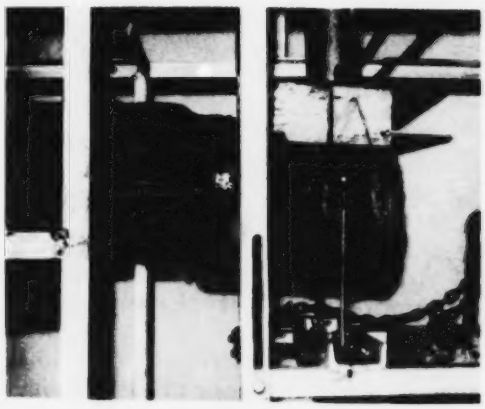

Figure 31. HST Joint and Concrete Pipe After Shear Test

It is recommended that a test sewer line be installed to demonstrate the actual performance of the polyolefin/hot melt adhesive system over a significant time period and to verify installation procedures on the job. This should be accomplished at a location suitable for controlled monitoring and observations in direct comparison with installed conventional joints.

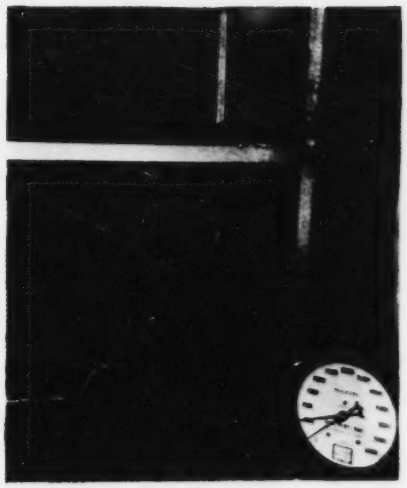

Figure 32. HST Joint on Clay Pipe After Shear Test

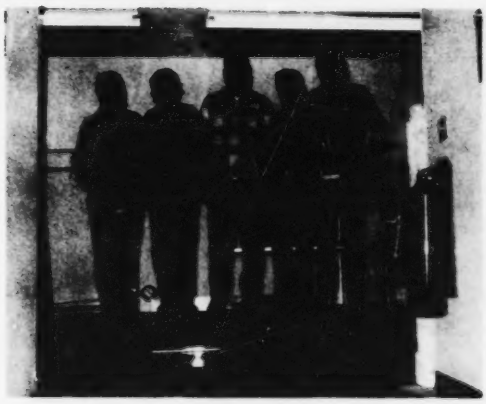

Figure 33. Special Polyolefin HST Joint Test

SECTION VIII

COST EFFECTIVENESS

The purpose of the program described in this report was to determine the technical feasibility of the HST joint and identify the best joint system. The emphasis of the program was placed on joint performance and simplicity of installation compared to existing systems. It was not the purpose of the program to necessarily produce a less expensive joint. Presumably a better joint, in terms of performance, would have a higher value and could cost more. Savings would accrue through less degradation to the environment, lower sewer cleaning and repair costs and lower system investment costs through infiltration elimination. The intent of the program was to identify a new system that performed better and would be economically practical compared to existing systems.

The investigation of sewer joint costs relevant to evaluation of the HST concept was divided into two catagories, those costs associated with installation, equipment and procedures, and those costs related directly to the materials. To develop these costs, contractors, pipe manufacturers, municipal authorities, published data and statistics were consulted.

Installation Costs

Analysis of the information developed, revealed that the cost of installation varies considerably geographically and from job to job.[16] The variation results primarily from changing labor rates, trench depth requirements and soil conditions. In addition, none of the national data and statistics found delineated cost per joint or cost per unit length directly. Although considerable detail was provided, individual cost items were consistently related to total job cost and not to quantities utilized. The statistics indicated that construction labor accounts for about 24.0 percent of capital investment in sewer lines, while pipe and joint materials account for 23.3 percent. Contractors were also extremely reluctant to disclose detailed information on their operating costs. For these reasons, it was not possible to adequately quantify the impact of HST joints on installation costs. Some conclusions pertaining to potential differences in costs can be made, however.

Trench depth and width (determinants of equipment and labor costs) should not change appreciably using HST joints. Manpower and placing equipment required to assemble a joint are determined primarily by pipe size and not type of joint. Therefore, the major installation costs for HST should be comparable to conventional systems.

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Some savings using HST could be anticipated. Undercutting for the bell, or tamping backfill under the pipe where blocks are used, could be eliminated without a bell. In addition, costs due to breakage of the bell in shipping and handling are currently reflected in the cost of construction and might be reduced. Repair costs for excavation and replacement necessitated by bells broken in use from soil shifting and shear loads must also be considered. It is evident that some reduction in installation and future operating costs might be anticipated by eliminating the bell.

The only added equipment cost associated with using HST is a small, portable heat source, the cost of which is estimated at less than $50. More sophisticated devices could cost more, however, they might also offer reduced installation time and, therefore, lower the cost of construction.

Material Costs

To evaluate HST joint material costs, it was necessary to develop the cost of providing conventional joints, primarily that of the bell and coupling materials. Manufacturers of each type of pipe were contacted. Various estimates for the direct manufacturing costs associated with the bell arrangement ranged from cost unknown, to no cost, to 50 percent of the cost. All sources were unable to reveal the actual costs involved.

In analyzing the economic impact of HST joints on sewer material costs 8 inch clay and concrete bell and spigot pipes 5 feet in length were taken as examples in the discussion throughout the remainder of this section. The clay pipe was assumed to have a rubber gasket joint, the concrete an "O" ring joint.

A review of business statistics for related manufacturing organizations revealed that the current direct manufacturing cost for such pipes should be about $3.35 for clay and $2.91 for concrete as shown in Table 3.[17, 18] This is based on a price to contractors of $5.00 and $4.35 respectively ($1.00 and $.87 per foot) from recent manufacturers' quotes for truckload quantities. That portion of cement pipe manufacturing costs resulting from the bell and joint materials could not be determined. However, it is possible to identify what those costs would have to be for HST joints to be substituted in the system.

The manufacturers of the polyolefin and polyvinyl chloride HST used in full scale testing indicated that the price of those materials to a contractor could be less than $1.50 per joint if demand was sufficient to justify large volume production. The actual volume basis for that price was not disclosed. Adding to that price the cost of providing adhesive (estimated at one pound per joint) at a quoted price of $.25 per pound, the total cost to a contractor for HST joint materials would be about $1.75 per joint as shown in Table 4.

	Clay Pipe[1]	Concrete Pipe[2]
Price to Contractor	$5.00	$4.35
Manufacturer's Gross Margin	1.65	1.44
Direct Manufacturing Cost	$3.35	$2.91

Note:

1. 8 inch diameter x 5 feet with rubber gasket coupling.
2. 8 inch diameter x 5 feet with "O" ring coupling.
3. 33 percent of sales average.

Table 3. Current Direct Pipe Manufacturing Cost

	Cost per 8 inch Joint
HST Tubing Cost to Contractor	$1.50
Applied Adhesive Cost	.25
HST Joint Materials Cost to Contractor	$1.75

Table 4. HST Joint Material Cost

If there were no final price difference between conventional joints and HST joints, the direct manufacturing cost would have to be reduced by about $1.75 per 8 inch pipe through elimination of the bell and existing joint materials to accommodate the cost of HST and adhesive. Thus a cost reduction of 52% for clay pipe and 60% for concrete pipe would be required for equal price substitution. Only the individual pipe manufacturers know to what extent such reductions might be achievable.

If the cost of the conventional systems cannot be reduced by eliminating the bell and joint materials, the total 8 inch joint cost would be increased by $1.75 or about 35 percent for clay pipe and 40 percent for concrete. With pipe and materials representing 23.3 percent of sewer capital cost, the use of HST joints in this case would increase total investment cost by about 8 to 9 percent. It was concluded that the actual economics must fall somewhere between the two cases presented.

As an example, if direct pipe manufacturing costs could be reduced by 25% using the HST system, total project cost increases of about 4 to 5 percent would have to be absorbed by the community. This would amount to about $4,500 on a $100,000 project. At a cost of capital of 8 percent, this added investment would cost the community $423 per year ($1.16 per day) over a 25 year investment life.

Likewise, to maintain economic equality with conventional joints, the added investment for HST would be expected to produce savings of the amount identified above ($1.16 per day). Based on the pipe size and cost used in Table 3 and its relation to total project cost, a $100,000 project could provide approximately 4.4 miles of conventional 8 inch sewer line. Assuming an allowable infiltration rate of 100 gallons per inch diameter per mile per day is experienced as a result of joint leakage, the total infiltration in the line would amount to 3,520 gallons per day. To be economically comparable to conventional joints the HST system would have to eliminate maintenance and incremental treatment costs related to that line and infiltration. The total of all costs eliminated would have to amount to $423 per year ($1.16 per day or $.27 per mile per day) in this example.

The key element in evaluating the economics of HST joints was felt to be the savings or credit allowed for elimination of the bell and conventional joint materials. There is some reason to believe that HST joints can be substituted with little, if any, added investment cost to the community. A final determination of this fact cannot be made at this time due to the proprietary nature of the required information. Likewise, it is not possible to present a definite quantitative determination of installation costs based solely on laboratory evaluation. From the information that is available, it was concluded that HST joints are feasible. The analysis suggests that potential cost differentials will fall within a range that is economically practical. Joint performance and installation costs must be finally determined in field use. Manufacturers must verify the cost of materials in the market place.

SECTION IX

PIPE REPAIR

As part of this program, an evaluation was conducted to consider methods for repairing broken or cracked joints using HST. It was felt that when a decision had been made to replace a badly broken or leaking joint, repair by an HST sleeve or wrap-around HST collar could simplify the operation.

In order to replace a conventional bell and spigot pipe, the pipes adjacent to the joint have to be pulled to allow the spigots to slip into the bells. This procedure results in four disturbed joints instead of two. By breaking away the cracked pipe and installing a plain-end pipe with HST joints, the adjacent pipes are not disturbed.

If the joint is leaking, but not broken, a wrap-around heat shrinkable collar could seal it. The material is received in flat strips of nonirradiated polyolefin. They are then wrapped around the pipe and the overlapping ends are heated until they fuse together. After the seam is made, they can be recovered around both the bell and barrel sections of the pipe. The wrap-around forms of HST are relatively new and their full potential is not known. Since this is a new product, specimens were not available for testing before completion of the program.

The labor and equipment involved in replacing a broken pipe or joint constitutes at least 50% of the repair costs. The cost of repair materials is minor in comparison.[5,16] As a result, sealing a leaking joint which is not broken or cracked by excavating the line and using HST materials may not be economically practical. One of the other sealing methods currently being used by the industry to seal joints internally might be better suited due to the high costs of uncovering the sewer line. If excavation is necessary, either the HST sleeve or wrap-around HST with adhesive would form a tighter and more durable joint than conventional joint systems as indicated by test results in this program.

SECTION X

SYSTEM APPLICATION

In designing an overall system for the installation of an HST joint sewer line, several considerations must be made. These involve the HST material to be used, the adhesive to be used and where the adhesive is to be applied, the heat source to be used, and the method of assembling the joint. As a result of the work accomplished in this program, a recommendation for each of these components can be made. A cross section of the recommended joint is shown in Figure 34. It is recommended that the basic HST joint system identified be demonstrated in actual field use and installation procedures verified.

HST Material and Adhesive Design

The heat shrinkable tubing acquired for the Phase II tests had an expanded diameter large enough to fit the bell of a sewer pipe and recovered small enough to fit the barrels of all three types of sewer pipe tested. By matching recovered and expanded diameters more closely to the outer diameter of plain-end pipe, material costs and recovery time could be reduced.

The addition of heat sensitive paint to the outer surface of the HST would insure that ample heat is applied to the tubing. Heat sensitive paint changes color when it reaches a predetermined temperature. This would make any cool spots stand out and aid both installers and inspectors of the pipe joint.

The adhesive can be on the interior surface of the tubing or placed on the outside surface of the sewer pipe during manufacture. This would ease and speed installation of the joints. Using tubing with adhesive preapplied to the interior surface is recommended as storage and handling conditions for the adhesive would be better. In addition, some tubing is currently manufactured with adhesives and already a part of the manufacturing process.

Heat Sources

The recommended heat source is gas, either from a torch or catalytic heating device.[8, 9] These types of heating devices eliminate the need for electricity in the pipe trench and loss of heat as with hot air blowers in high winds. The heat source should be able to encompass the HST joint to achieve uniform shrinkage, standardized joint quality and a minimum installation time.

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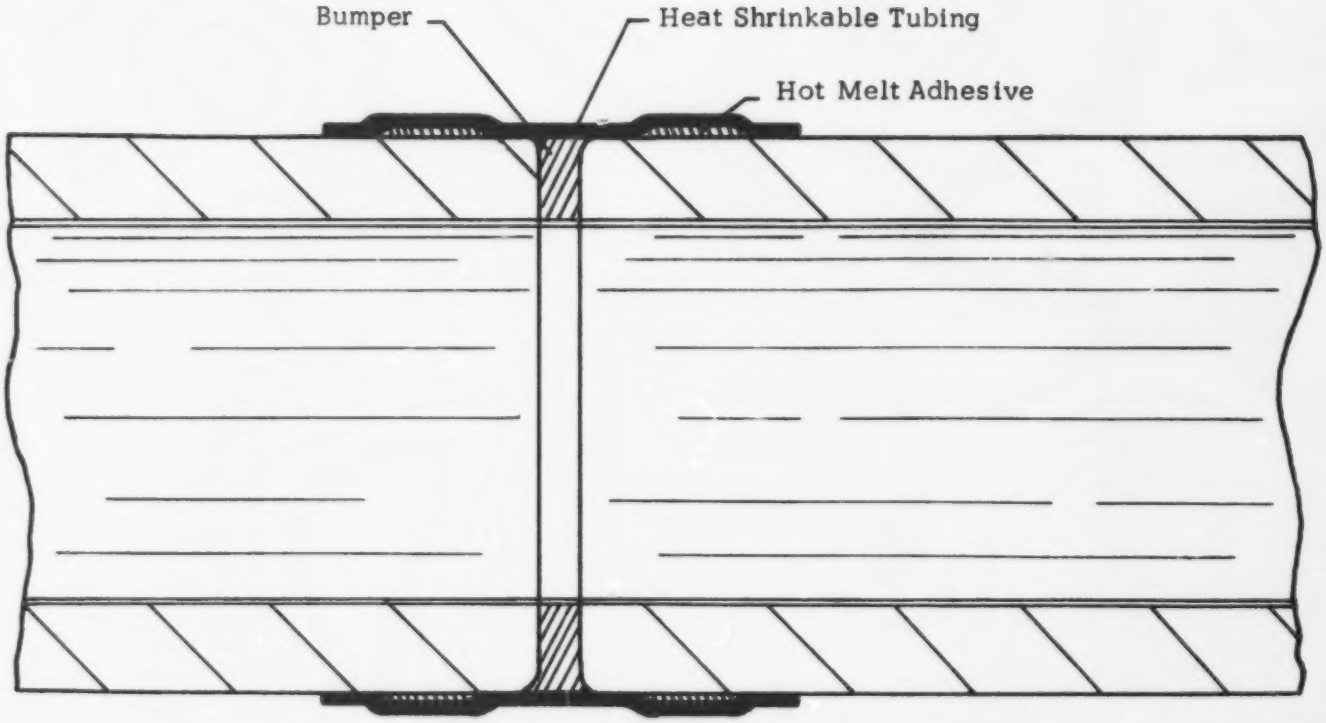

Figure 34. Cross Section of HST Joint

Sewer Pipe Modifications

Although HST materials perform equally well on bell and spigot or plain end pipe, it is recommended that plain end pipe be specified and used. Reductions in total installed cost through elimination of the bell, closer sizing of unrecovered HST to the pipe and greater ease of placing the HST may be experienced. As previously mentioned, the barrel ends of the pipe should not be butted together. This could result in chipping and cracking of the pipe ends during installation and from shifting soil loads. A bumper surface of suitable material should be manufactured on one end of each sewer pipe. When the pipes are installed there would be one bumper at each joint. Besides cushioning the ends of the pipe, the bumper would reduce eddies in flow over the joint.

Installation Procedures for HST Joints

Only minor changes in equipment and procedures presently being used to install sewer lines would be required to install HST joints. Instead of recessing the bottom of the trench to receive the bell on commercial pipe, the pipe ends for the HST joint would have to be temporarily elevated 3 to 4 inches with blocks to allow the heat to reach the lower side of the joint. After the tubing recovered, the blocks would be pulled out and the pipes would drop into place. The heat shrinkable tubing requires approximately 5 to 10 minutes to cool at room temperature. During this time, it is still very soft and flexible and final positioning of the pipe can be accomplished. See Figure 35.

A proposed system for assembling HST joints above ground was considered and is depicted in Figure 36. Such a system could cut labor costs and installation time. The equipment involved in this process would include a flat bed trailer with the heating device and materials loaded on it. Two sections of pipe would be positioned on rollers with the HST around the joint. They would then pass through a heat chamber and the HST would be recovered around the pipe ends. The rollers would then carry the joint through a refrigerated water bath to set the hot melt. After the bath, the joint would be cooled sufficiently to allow the pipes to be lowered into the trench from the vehicle. The vehicle could move forward one pipe length at a time providing a continuous operation. By using this procedure, narrower trenches could be used in some instances and there would be minimum requirements for men working in the trench.

The characteristics of the HST joints, particularly tensile strength, offer the opportunity for significant changes and improvements in current sewer construction practice. These opportunities should be evaluated and demonstrated. It is recommended that further investigation and development of systems such as that described be initiated upon field use verification of the basic HST joint concept.

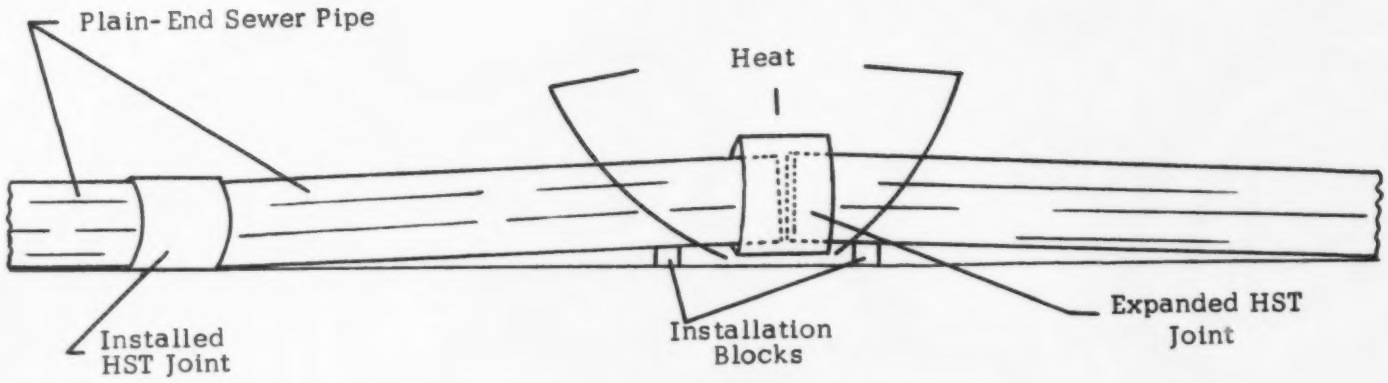

Figure 35. Assembling HST Joint in the Trench

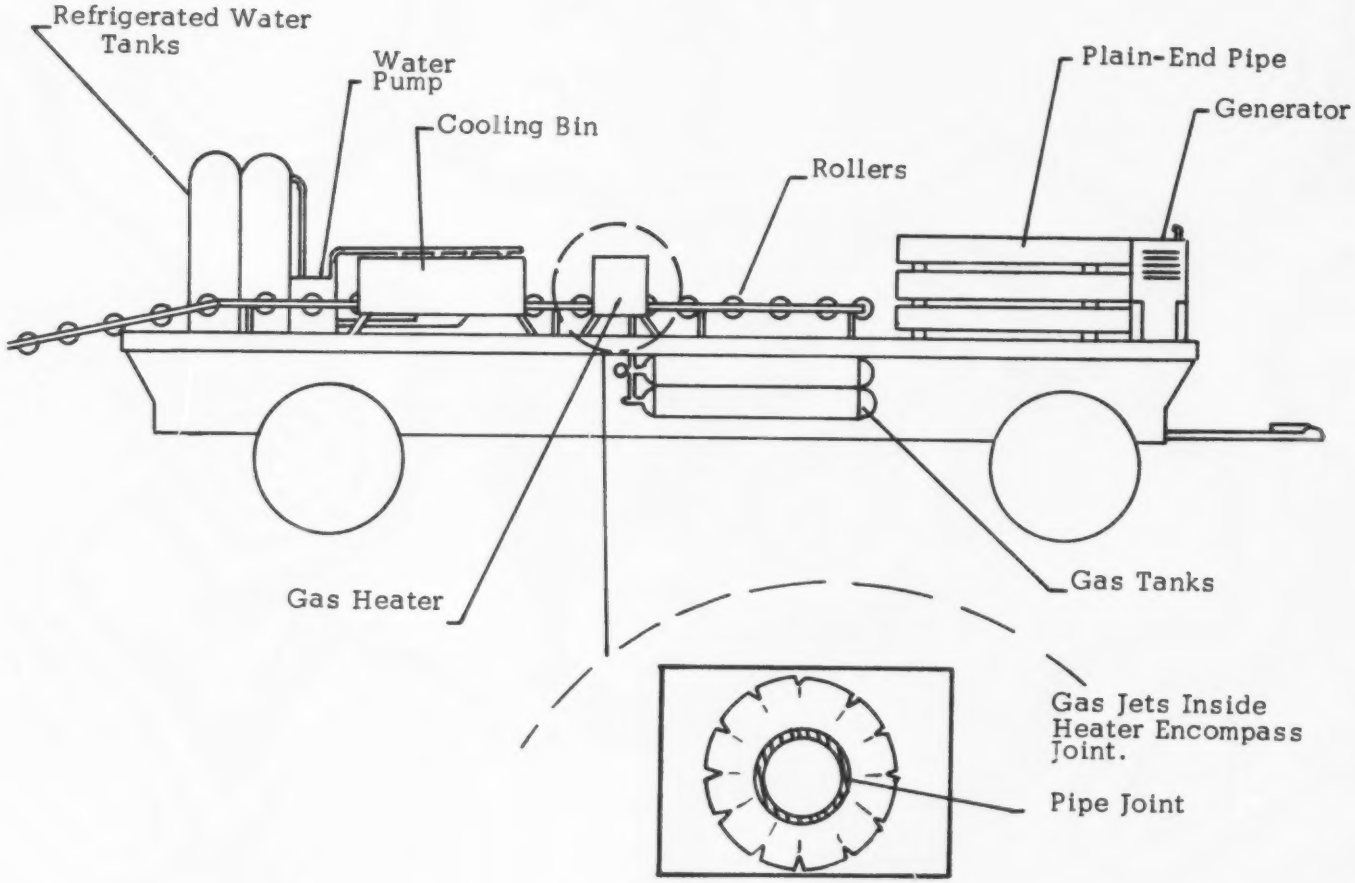

Figure 36. Proposed Equipment for Assembling HST Joints Above Ground

SECTION XI

ACKNOWLEDGMENTS

We would like to thank the Water Quality Office of the Environmental Protection Agency for their assistance during this program. In particular, we wish to thank Mr. W. A. Rosenkranz, Chief, Storm and Combined Sewer Pollution Control Branch; Mr. George Putnicki, Director, Office of Contracts & Grants for Research, Development & Demonstration, Region VI; and Mr. Robert Hiller, Deputy Director, Office of Contracts & Grants for Research, Development & Demonstration, Region VI.

We also express our appreciation to the many companies and individuals who furnished comments and information pertaining to products and practices related to the program. In particular, we would like to thank E. I. Dupont De Nemours & Company, Can-Tex Industries Division of Harsco Corporation, Raychem Corporation, and Rally Industries for their assistance and products furnished for the program.

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SECTION XIII

GLOSSARY

HST - Heat shrinkable tubing.

Recovered Diameter - The inner diameter of the HST after it shrinks.

Recover - In reference to HST, to shrink.

Expanded Diameter - The inner diameter of the HST before it is heated and shrunk.

House Laterals - The sewer line which connects a building to a main sewer line.

SECTION XIV

APPENDICES

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APPENDIX A

HEAT-SHRINKABLE TUBING
LITERATURE REVIEW

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HEAT-SHRINKABLE POLYMERS

A Literature Search

Prepared By

Martha Bates
Literature Searcher

I.I.S. SEARCH NO. 620

May 21, 1970

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HEAT-SHRINKABLE POLYMERS

Introduction

A survey of a portion of the technical and marketing literature on heat-shrinkable plastics and rubber has been completed, as you requested. Emphasis was placed on tubing, but citations on both film and tubing were included due to the scarcity of material on the latter. Mechanical and chemical properties of heat-shrinkable tubing, shapes and sizes available, manufacturers, and tube-shrinking devices were of interest.

The following sources were used in the course of the search:

Applied Science and Technology Index, 1964 - April, 1970.
Chemical Buyer's Guide, 1970.
A Directory of Information Resources in the United States, 1965.
Directory of Special Libraries and Information Centers, 1968.
Modern Plastics, January - April, 1970.
Modern Plastics Encyclopedia, 1970.
Plastics and Polymers, 1969 - February, 1970.
Plastics Monthly, 1968-1969.
Plastics Technology, 1969 - April, 1970.
Thomas Register, 1969.

In addition, recent issues of Business Periodicals Index, Chemical Abstracts, Electrical and Electronics Abstracts (Science B), Engineering Index, Gas Abstracts, Instrument Abstracts, the NASA report literature, Paper Chemistry Institute Abstracts, Petroleum Abstracts, and the U.S. Government Research and Development Reports were scanned. Also various other directories, texts, and encyclopedias were consulted but yielded no pertinent information. Patents as such were not searched, but relevant ones were noted during the survey. No single comprehensive listing of manufacturers of heat-shrinkable tubing and/or films was found, but isolated names were uncovered. We could have copied all the manufacturers the various kinds of polymers known to be used in the shrink process, but this did not seem worthwhile because these same polymers (such as PVC and polyethylene) are used in so many other ways. However, this can be done if you wish, and also a patent search can be undertaken upon your authorization.

The report is divided into four major sections, with the first two subdivided into two parts each. The first covers heat-shrinkable tubing, with Part A noting full-length articles and Part B abstracts and citation. Section II is comprised of material on heat-shrinkable films such as those used for packaging and wrapping. Parts A and B correspond to those of Section I. Section III covers manufacturers, both of equipment

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and polymers, while Section IV highlights research centers and special libraries which you might consult for further information. The citations in IB and IIB are arranged chronologically, most recent first, while Section III and IV are arranged alphabetically by name of the company or center. Separate from the search itself is a guide to heat-shrinkable plastics located in the journal Electronic Engineer, March, 1969.

It is hoped that this report will be of use in your project.

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SOUTHERN METHODIST UNIVERSITY
HEAT-SHRINKABLE POLYMERS
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APPENDIX B

AMERICAN SOCIETY FOR TESTING AND MATERIALS
PERTINENT EXTRACTS FROM
SPECIFICATIONS RELEVANT TO SEWER PIPE JOINTS

ASTM C594-66T (Accepted 11-16-66)
COMPRESSION COUPLINGS FOR VITRIFIED CLAY PLAIN-END PIPE
(Minimum Requirements)

TABLE 1 - TESTS FOR RUBBER MATERIALS

Test	Test Requirements	ASTM Test Method
Chemical resistance		D 543[5]
1 N sulfuric acid	no weight loss	
1 N hydrochloric acid	no weight loss	
Tensile strength	1000 psi min 450% min elongation at break	D 412[5]
Hardness	60 $\pm$ 5	D 2240[5] (Shore A durometer)
Accelerated oven aging	decrease of 10% max of original tensile strength decrease of 10% max of original elongation	D 573[3] (7 days at 70 - 1 C)
Compression set	decrease of 25% max of original deflection	D 395[3] Method B (70 C for 22 hr)
Water absorption	increase of 5% max of original weight	D 471[3] as follows: immerse 0.075 by 2 by 2 in. in distilled water at 70C for 7 days.
Ozone resistance	rating no. 1	D 1171[3]
Low temperature brittle point	no fracture at -40 F	D 746[3]

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5. Test Requirements for Joints

5.1 Pipe joints shall meet the following requirements:

5.1.1 The pipe joints shall be designed in a manner to achieve a residual compression of at least 30 psi between the coupling and the pipe barrel.

5.1.2 The joint shall exhibit sufficient flexibility to allow the following deflections without visible leakage when tested with an internal 10-ft head of water (4.3 psi) for a period of 1 hr for each test condition. The tests shall be performed at temperatures of the water, pipe and atmosphere within a range of 60 to 75 F. These tests will be construed to demonstrate exfiltration characteristics.

5.1.2.1 Test Condition I.-- The ends of the test line (two lengths of joined pipe) shall be restrained against longitudinal movement. The pipe shall be deflected in any direction for the distances stated in Table 2. The deflection shall be the distance the free end of one pipe moves away from the center line in any direction while the other pipe remains fixed.

5.1.2.2 Test Condition II: Coupling without Shear Ring--There shall be no leakage when tested under conditions outlined in 5.1.2 if the jointed ends shall be deflected relative to one another in any direction, either longitudinally or perpendicularly to the pipe axes a distance of $^1/_{24}$ in./in. of pipe diameter.

TABLE 2 - DEFLECTION PER FOOT OF PIPE LENGTH

Nominal Diameter, in.	Deflection per Foot of Pipe Length, in.
4 to 12, incl.....	$^1/_2$
15 to 24, incl.....	$^3/_8$
27 to 36, incl.....	$^1/_4$

5.1.2.3 Test Condition II: Coupling with Shear Ring--Instead of the deflection test specified in 5.1.2, the following shear test on couplings with shear rings may be substituted. When a weight of 150 lb/in. of nominal diameter is uniformly applied over an arc of not less than 120 deg and along a longitudinal distance of 12 in. at the end of the pipe immediately adjacent to the coupling of the assembled joint, there shall be no leakage when tested under the conditions outlined in 5.1.2.2. The pipe in this laboratory test shall be supported on adequate blocks placed immediately behind the coupling.

6. Field Performance and Acceptance

6.5 Joints shall sustain a maximum limit of 0.40 gal/in. of diameter/hr/100 ft of line when field tested by actual infiltration conditions. If exfiltration testing is required or necessary, the joints shall perform equally well, except that an allowance of an additional 10 per cent of

gallonage shall be permitted for each additional 2-ft head over a basic 2-ft minimum internal head.

ASTM C 425-66T (Accepted 11-16-66)
COMPRESSION JOINTS FOR VITRIFIED CLAY BELL AND SPIGOT PIPE
(Minimum Requirements)

TABLE I - TESTS FOR PLASTIC MATERIALS

Test	Test Requirements	ASTM Test Method
Chemical resistance		D 543
1 N sulfuric acid	no weight loss	
1 N hydrochloric acid	no weight loss	

TABLE 2 - TESTS FOR RUBBER MATERIALS

Test	Test Requirements	ASTM Test Method
Chemical resistancw		D 543[3]
1 N sulfuric acid	no weight loss	
1 N hydrochloric acid	no weight loss	
Tensile strength	2000 psi min. 500% min elongation at break	D 412[3]
Hardness	35 min 50 max	D 2240[3](Shore A Durometer)
Accelerated oven aging	maximum decrease of 20% of original tensile strength maximum decrease of 25% of original elongation	D 573[4] (7 days at 70 ± 1 C)
Compression set	maximum decrease of 16% of original deflection	D 395[4], Method B (70 C for 22 hr)
Water absorption	maximum increase of 5% of original weight	D 471[4] as follows: Immerse 0.075 in. by 2 in. by 2 in. in distilled water at 70C for 7 days
Ozone Resistance	Rating no. 1	D 1171[4]

TABLE 3 - DEFLECTION PER FOOT OF PIPE LENGTH

Nominal Diameter, in.	Deflection per foot Pipe Length, in.
4 to 12, incl.....	1/2
15 to 24, incl.....	3/8
27 to 36, incl.....	1/4

6. Test Requirements for Joints

6.1 Pipe joints shall meet the following requirements:

6.1.1 The joint shall exhibit sufficient flexibility to allow a deflection in any direction per ft of pipe length for various pipe diameters as stated in Table 3, and the joint, when deflected, shall show no visible leakage when being tested under an internal 10-ft head of water pressure (4.3 psi). The ends of the test line shall be restrained only in an amount necessary to prevent longitudinal movement. The deflection shall be measured as the distance the free end of one pipe moves away from the center line in any direction, while the other pipe remains fixed.

6.1.2 The pipe joints shall present sufficient resistance to shear loading to meet the following test: when a weight of 150 lb/in. of nominal diameter is uniformly applied over an arc of not less than 120 deg and along a longitudinal distance of 12 in. at the spigot end of the pipe immediately adjacent to the bell of the assembled joint, there shall be no visible leakage when an internal 10-ft head of water pressure (4.3 psi) is applied for a period of 1 hr after application of the shear load, with the temperature of water, pipe, and atmosphere within a range of 60 to 75 deg F. The pipe in this laboratory test shall be supported on adequate blocks placed immediately behind the bell. This test shall be construed to demonstrate exfiltration characteristics.

7. Field Performance and Acceptance

7.5 Joints shall sustain a maximum limit of 0.40 gal/in. of diameter/hr/100 ft of line when field tested by actual infiltration conditions. If exfiltration testing is required or necessary, the joints shall perform equally well, except that an allowance of an additional 10 per cent of gallonage shall be permitted for each additional 2-ft head over a basic 2-ft minimum internal head.

ASTM C 428-69a (Accepted 11-14-69)
ASBESTOS-CEMENT NONPRESSURE SEWER PIPE

Joint Tightness

5. (a) The purchaser by designation with his order may require that assembled pipes and couplings pass the following performance tests without leakage:

(1) Straight Alignment--A hydrostatic pressure test shall be made on an assembly of two sections of pipe, properly connected with a coupling in accordance with the joint design. An equivalent alternative may be a single pipe with a coupling on each end. The assembly shall be subjected to an internal hydrostatic pressure 10 psi (0.7 kgf/cm^2) for 10 min and any leakage shall be considered a failure of the test requirement.

(2) Maximum Deflected Position--Upon completion of the test for pipes in straight alignment in accordance with Section 5(a) (1), deflect the test sections 5 deg for 12 in. and smaller diameters and 3 deg for 14 in. and larger diameters (with one half of the deflection being between each pipe and the coupling) and subject it to an internal hydrostatic pressure of 10 psi (0.7 kgf/cm^2) for 10 min. Any leakage shall be considered a failure of the test requirement.

(b) Test one sample of at least one size unless some other arrangement is made with the purchaser by designation with his order. At the option of the purchaser, the sample of the pipes and couplings to be tested may be selected by him. Instead of requiring performance of these tests, the purchaser may require the manufacturer to certify that the pipes and couplings will pass the tests enumerated in this section.

ASTM C 443-70 (Accepted 2-6-70)
JOINTS FOR CIRCULAR CONCRETE SEWER AND CULVERT PIPE, USING RUBBER GASKETS

Note 1--The purchaser of pipe with rubber gasket joints should carefully investigate the adequacy and performance of the rubber gasket joint proposed for use. The infiltration or exfiltration in a pipe line made with these joints should not exceed 0.60 gal/in. (0.002 m^3/25 mm) of internal pipe diameter per 100 ft (30.48 m) of pipe line/h, where the maximum hydrostatic head at the center line of the pipe does not exceed 25 ft (7.62m). The purchaser may specify other infiltration or exfiltration requirements.

8. Performance Requirements for Joints

8.1 The purchaser may require that assembled joints pass the following performance tests without leakage at the joints:

8.1.1 Pipes in Straight Alignment--Hydrostatic pressure tests on joints shall be made on an assembly of two sections of pipe, properly connected in accordance with the joint design. At the option of the purchaser a second such test may be required. Suitable bulkheads may be provided within the pipe adjacent to and on either side of the joint, or the outer ends of the two joined pipe sections may be bulkheaded. No mortar or concrete coatings, fillings, or packings shall be placed prior to watertightness tests. After the pipe sections are fitted together with the gasket or gaskets in place, the assembly shall be subjected to an internal hydrostatic pressure of 10 psi (1 kg/cm^2) for 10 min. Moisture or beads of water appearing on the surface of the joint will not be considered as leakage. At the manufacturer's option, the test period may be extended up to 24 h.

8.1.2 Pipes in Maximum Deflected Position--Upon completion of the test for pipes in straight alignment in 8.1.1, the test sections shall be deflected to create a position $^1/_2$ in. (12.7 mm) wider than the assembled position on one side of the outside perimeter of each joint and shall be subjected to an internal hydrostatic pressure of 10 psi for 10 min. Moisture or beads of water appearing on the surface of the joint will not be considered as leakage.

APPENDIX C

CONVERSION FORMULA FOR PHASE I SHEAR TEST

Stress = Pounds of shear load / Area in sq. inches = PSI

This formula can compare the shear load applied to the 1 inch diameter HST with a wall thickness of 0.035 inch to an 8 inch HST joint with a wall thickness of 0.122 inch. By taking a cross section of the HST joint at the shear point and finding the area of that material, the area can be divided into the shear load to determine the PSI of that load.

EXAMPLE:

If the 8 inch diameter HST joint has:

1. Wall thickness = 0.122 inch
2. Inner diameter (I.D.) = 9.75 inches
3. Outer diameter (O.D.) = I.D. + 2 (wall thickness) = 9.99 inches
4. Load = 1200 pounds ..... ASTM specification

Stress = Load / Area

Area = 3.14 / 4 $(O.D.)^2 - (I.D.)^2$
Area = 3.14 / 4 $(99.8) - (95.1)$
Area = 3.69 sq. in.

Stress = 1200 lbs. / 3.69 sq. in. = 325.2 PSI

Knowing that an 8 inch sewer pipe has 325 PSI at 1200 pounds shear load, the minimum load for the 1 inch HST joint can be determined. The same procedure is followed.

The 1 inch diameter HST joint has:

1. Wall thickness = 0.035 inch
2. I.D. = 1.2 inches
3. O.D. = 1.27 inches
4. Load = 43 pounds

Stress = Load / Area

Area = 3.14 / 4 $(O.D.)^2 - (I.D.)^2$
Area = 0.13 sq. in.

Stress = 43 pounds / 0.13 sq. in. = 330 PSI

Note that the 8 inch HST joint must withstand 325 PSI under 1200 pounds of shear load, and that the 1 inch HST joint must withstand 330 PSI under 43 pounds of shear load. Consequently all 1 inch HST joints must withstand a minimum of 43 pounds shear load, or the joint is a failure.

APPENDIX D

MATERIALS UTILIZED AND TESTED

HEAT SHRINKABLE TUBING

Laboratory Testing

Generic Name	Brand Designation	Manufacturer
Polyolefin	RNF 100	Raychem Corporation
Polyolefin	HIX 2	Rally Industries Inc.
Polyvinyl Chloride	FIT 105-2	Alpha Wire Corporation
Silicon Rubber	Silastic 1412	Dow Corning Corporation
Neoprene	NT-2	Raychem Corporation
Neoprene	Penntube VII	Penntube Plastics Inc.
FEP Teflon	FEP 177	E. I. Dupont De Nemours & Co.
FEP Teflon	SMT II	Penntube Plastics Inc.
TFE Teflon		Zeus Industrial Products Inc.
TFE Teflon	Penntube I	Penntube Plastics Inc.
Viton		Raychem Corporation
Kynar		Raychem Corporation
Polyethene & Adhesive	TPS 1000	Raychem Corporation
Polyethene & Adhesive	WRS	Raychem Corporation

Full Scale Testing

Generic Name	Brand Designation	Manufacturer
Polyolefin	TPS 10750	Raychem Corporation
FEP Teflon		E. I. Du Pont De Nemours & Co.
Polyvinyl Chloride		Rally Industries Inc.

ADHESIVES

Laboratory Testing

Generic Name	Brand Designation	Manufacturer
Butyl Adhesive Tape	SFTS 1	Sigma Industries Inc.
Hot Melt	TPX 327	Raychem Corporation
Hot Melt	394 A	Raychem Corporation

Full Scale Testing

Generic Name	Brand Designation	Manufacturer
Hot Melt	CC 150	Stuck Adhesives Inc.
Adhesive Tape	SFTS 1	Sigma Industries Inc.
Hot Melt	DA-2	3-M Company
Hot Melt	80-5322-0	Paisley Products, Inc.
Hot Melt	Superseal	Electro-Seal Corp.
Hot Melt	Electro-Stix I	Electro-Seal Corp.
Hot Melt	M 5L	Eastman Chemical Products Inc.

Full Scale Testing (cont.)

Generic Name	Brand Designation	Manufacturer
Hot Melt	M5W	Eastman Chemical Prod. Inc.
Epoxy	Plastilock 729	B. F. Goodrich Adhesive Prod.
Epoxy	Plastisol 370-569	B. F. Goodrich Adhesive Prod.
Film Adhesive	367-147 Sealant	Hysol Corp.
Epoxy	CPRL 367-109	Hysol Corp.

COMMERCIAL SEWER PIPE JOINTS

Full Scale Testing

Type	Manufacturer
Clay, Bell and Spigot Pipe	Can-Tex Industries
Asbestos-Cement Nonpressure Sewer Pipe	Johns-Manville Transite Pipe
Concrete, Rubber Gasket	Gifford-Hill Pipe Company
Clay, Compression Couplings	Can-Tex Industries

APPENDIX E

FULL SCALE TEST DATA

Test No.	Internal Pressure PSI	Deflected Internal Pressure PSI	Shear LBS	Tensile LBS
1.	15.0	15.0	3600	146
2.	12.4	15.0	2900	65
3.	13.0	10.5	3800	174
Average	13.5	13.5	3400	128

Table 1. Asbestos-Cement Test Results

Test No.	Internal Pressure PSI	Deflected Internal Pressure PSI	Shear LBS	Tensile LBS
1.	15.0	12.0	2400	68
2.	11.5	10.4	2600	195
3.	12.6	8.5	1900	137
Average	13.0	10.3	2300	133

Table 2. Clay, Bell and Spigot, Test Results

Test No.	Internal Pressure PSI	Deflected Internal Pressure PSI	Shear LBS	Tensile LBS
1.	Failed	Failed	Failed	105
2.	15.4	11.0	3400	271
3.	13.7	9.2	2600	188
Average	9.7	6.7	2000	188

Table 3. Concrete and Rubber Gasket Joint Test Results

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Test No.	Internal Pressure PSI	Deflected Internal Pressure PSI	Shear In.	Tensile LBS
1.	9.7	11.3	7/16	61
2.	8.5	7.7	3/8	78
3.	10.4	10.0	9/16	94
Average	9.5	10.0	7/16	78

Table 4. Clay, Compression Coupling Test Results

Test No.	Internal Pressure PSI	Deflected Internal Pressure PSI	Shear LBS	Tensile LBS
1.	15.0	15.0	Failed	900
2.	15.0	15.0	5300	900
3.	15.0	15.0	2800	900
Average	15.0	15.0	4100	900

Table 5. Polyolefin HST, CC150 adhesive, and Clay plain-end Pipe

Test No.	Internal Pressure PSI	Deflected Internal Pressure PSI	Shear LBS	Tensile LBS
1.	15.0	15.0	4800	900
2.	15.0	15.0	5600	900
3.	15.0	15.0	5100	900
Average	15.0	15.0	5200	900

Table 6. Polyolefin HST, CC150 Adhesive, Asbestos-Cement and Plain-End Pipe

Test No.	Internal Pressure PSI	Deflected Internal Pressure PSI	Shear LBS	Tensile LBS
1.	15.0	15.0	5700	900
2.	15.0	15.0	2800	900
3.	15.0	15.0	4400	900
Average	15.0	15.0	4300	900

Table 7. Polyolefin HST, CC150 Adhesive, and Concrete Plain-End Pipe

APPENDIX F

TECHNICAL DATA SUBMITTED BY RALLY INDUSTRIES PERTAINING TO THE 8 INCH RECOVERED POLYVINYL CHLORIDE HEAT SHRINKABLE TUBING MANUFACTURED FOR THIS PROGRAM

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HEAT SHRINK RIGID PVC SLEEVING

INTRODUCTION

A sub-contract to develop a heat shrink sleeve from Rigid PVC was established under prime contractor, WESTERN RESEARCH CORP., Richardson, Texas. The prime development project involved a method of producing heat shrink sleeves of rather large dimensions for sealing butt joint ceramic clay or cast iron pipe subject to seismic shifts and other joint hazards.

GENERAL SPECIFICATIONS

1. The basic sleeve material must have low water absorption properties and good resistance to petroleum hydrocarbons and chemicals.

2. The sleeve requires sufficient tensile strength and elongation to resist a finished joint bending test involving one fixed length while the second length is moved through an arc of 1" per foot of length.

3. The sleeve must be capable of shrinking using hot air methods from an original inner diameter of 11" to a final diameter of 8" and affect a sealed joint using accepted hot melt adhesives that will melt during the heat shrink process.

HEAT SHRINK THEORY

The most probable structure of useful polymers is a random tangled arrangement of long chain molecules. Structural strength is dependent upon intermolecular attractive forces and the inability of the molecular chains to move freely.

If the molecular structure is stretched in a relatively cool state, realignment of the molecular structure occurs and the stresses are locked in by intermolecular forces which resembles crystal structure. The molecular locking areas are called spherulites or crystalites.

A second way to lock in molecular stresses is through the use of chemical cross links. In rubber this is accomplished through "vulcanization" with sulfur bridges. Direct carbon to carbon bonds occur in adjacent molecular chains through the use of peroxide crosslinking agents or by electron beam irradiation of certain polymers.

The locked in stresses can be relaxed by heating the structure above its "glass transition temperature" which allows molecular rearrangement or

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shifting of the chain structure back to its original dimensions, resuming its original tangled relaxed state.

Advantage can be taken of this principle by inducing stresses in rigid PVC by stretching at a relatively low temperature. The stresses are locked in by intermolecular forces - crystalites - and relaxed to shrink to its original dimensions by heating above its glass transition temperature (above 170°F).

STRUCTURE

a.) Plastic Sheeting

To apply the concept, rigid Type II PVC sheeting is stretched approximately 100% in the longitudinal direction and at a temperature of 190-250°F. This is accomplished by speeding up the take off of the calender train during sheet production.

The stretched sheet when relaxed at 210°F will shrink up to 30% of its original calendered dimension and at 330°F the sheet will shrink up to 50% of the calendered stretched length (100% based on the final relaxed dimensions).

b.) Adhesive

The adhesive requirements are very rigorous involving the following points:

1.) Maximum specific adhesion to rigid PVC.
2.) Heat resistance to above 300°F to maintain bond strength during shrink process.
3.) Sufficiently thermoplastic to allow shrinkage to occur at temperature of 200°F-300°F.

c.) Hot Melt

The hot melt affects the seal between the sleeve and the pipe. Besides forming a hot melt seal during the heat shrink process, the hot melt must be resistant to water, chemicals, hydrocarbons, etc.

PRODUCTION PROCEDURE

Shrink sleeves are produced by wrapping and bonding stretched PVC sheeting on a circular mandrel of the desired dimensions.

In this way sleeves of any dimension can be made with minimum tooling cost. The dimensional change will be directly proportional to the shrink built into the PVC sheeting.

Sleeve building procedure follows:

a.) Building Mandrel

A collapsible mandrel can be built from relatively light sheet metal locked to the proper initial dimensions (inner diameter). This design should permit good internal heat transfer and sufficient inner peripheral collapse to permit removal of the finished sleeves. Accurate, constant sectional dimensions of the mandrel are necessary to guarantee accurate wrapping geometry.

b.) Cement Application

Cement can be applied by brush, spray or roller coat to the sheeting. In this particular construction two coats of a 30% solids polyester cement was applied to produce approximately 1 mil dry film thickness. A single coat of the same cement was applied to the opposite side of the sheet and allowed to air dry for a minimum of 15 minutes before assembly.

c.) Mandrel Wrapping

Dry coated sheeting having a length equivalent to the number of circumferential wraps required for the proper thickness plus 30% of circumference for overlap reinforcement. It is necessary to align the sheet and the mandrel properly in order to produce a smooth tight wrap, free of wrinkles and potential trapped air.

d.) Pressure Application

Ply to ply pressure is necessary to produce an intimate contact to guarantee fusion of the cement films during the heat bonding process. This also prevents the laminate from uncoiling during the heat bonding process. The necessary pressure is applied by stretching an external rubber sleeve over the coiled laminated structure. A pressure sleeve of temperature resistant rubber designed for medium modulus properties will supply sufficient bonding pressure when elongated approximately 50% and has a sectional thickness of .060" to .090".

e.) Heat Bonding Cycle

The assembled mandrel with the dry adhesive coated PVC sheeting, prepared with the external rubber pressure sleeve, is placed in a forced draft air oven and heated 15 minutes at 250°F.

The actual attained temperature of the sleeve is in the order of

200-230°F. The heat causes the PVC sheeting to shrink sufficiently to apply the additional necessary pressure for structural ply bonding.

The dry adhesive film coating is heat activated at 210°F to 220°F which fuses the structure into a tight uniformly bonded sleeve.

After coating, the mandrel is unlocked, slightly collapsed and the sleeve removed and trimmed to 8" or whatever specified lengths.

FINAL TESTING

a.) Inspection

The sleeves are checked for blisters or non-laminated areas. This can be done by flexing the sleeves. Any non-laminated areas produce a distinctive frictional or "cracking" sound.

b.) Percent Shrink Vs. Temperature

Typical sleeve sections are placed in circulating air ovens at 200°F and 300°F for 15 minutes.

Minimum percent shrink as measured by circumferential dimensions before and after heat treatment follow:

	% Shrink - minimum
200°F	20%
300°F	50%

c.) Mandrel Shrink

To an 8" diameter (OD) sheet metal mandrel two strips of hot melt adhesive (cross section 1/4" x 1/2") is wrapped around the test mandrel 7-1/2" apart. An 11" ID PVC shrink sleeve is centered on the prepared 8" mandrel and placed in an oven 5 minutes at 275°F.

The PVC sleeve must shrink tightly onto the mandrel producing a sealed structural simulated joint. The hot melt must exude from the end of the sleeve forming a continuous seal.

ADDITIONAL DESIGN POSSIBILITIES

1. Evaluate heat activated cements that can be cast into films which in turn can be coiled as an interleaf between PVC plies and heat fused as described above.

2. Evaluate high temperature resistant pressure sensitive adhesives such as Silicones that would allow simple pressure wrapping of sleeves and heat shrinking at 300°F.

3. Investigate mechanical riveting using metal or plastic gussetts and rivets at the PVC ply overlap area. Gussett seals could be made using extra hot melt sealant in this area.

4. Better hot melt design would be achieved by heat shrinking annular grooves circumferentially around the PVC sleeves to contain a preformed ring of hot melt sealant.

   This could be done during the heat setting process of the adhesive over a shaped mandrel containing annular ribs.

5. A heat shrink heating device should be designed to distribute hot air at 350°F to 400°F in a flow pattern from one end of the sleeve to the other with air flow outside and inside of the sleeve for uniform heating.

   This could be designed as a split hot air oven with an outside annular space of 2"-3" greater than the shrink sleeve. Hot air from a gas fired oven would be forced through and over the sleeve affecting rapid and even heat transfer eliminating most of the heat sink problems of the cold pipe.

   Considerable development is needed to develop field methods for delivering uniform heat to the sleeve to produce an even uniform shrink without the necessity of heating the pipe or the great out-of-doors.

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HEAT SHRINKABLE TUBING AS SEWER PIPE JOINTS

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Heat shrinkable tubing, hot melt adhesives, sewer joint tests

27 Abstract Preliminary testing had indicated that commercial sewer pipe might be in tight waterproof joints using the heat shrinkable plastic tubing (HST) dev used extensively in the electronics and aerospace industries. Laboratory studie materials and joints were conducted to determine their characteristics and their and economic feasibility. A wide variety of HST materials and joints were teste addition to conventional joints for clay, concrete and asbestos-cement pipes.

The results of both small scale tests and full scale tests using commercial 8 inc pipe indicated that a polyolefin with a polymeric base hot melt adhesive produce most durable, watertight joints and were significantly superior in performance c to existing pipe joining mechanisms. In addition, the cost analysis indicated t joints are economically feasible and compare favorably to conventional joints wh considering both material and installation costs. The HST joint requires no sign departure from current installation practice and is equally adaptable to repair of commercial pipe and joints. Field development and in-use demonstration of the system is recommended.

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